OU/C

HOUSE OF COMMONS SESSION 2000–2001

SCIENCE AND TECHNOLOGY COMMITTEE

Third Report

SCIENTIFIC ADVISORY SYSTEM: SCIENTIFIC ADVICE ON CLIMATE CHANGE

Report, Proceedings of the Committee, Minutes of Evidence
and Appendices

Ordered by The House of Commons *to be printed*
28 February 2001

PUBLISHED BY AUTHORITY OF THE HOUSE OF COMMONS
LONDON – THE STATIONERY OFFICE LIMITED
£14·70

M21500

This book is due for return on or before the last date shown below.

Don Gresswell Ltd., London, N21 Cat. No. 1207 DG 02242/71

22501828181

HOUSE OF COMMONS SESSION 2000–2001

SCIENCE AND TECHNOLOGY COMMITTEE

Wellcome Library
M21500
Scientific advisory system : scientific advice on climate change : report, proceedings of the Committee, minutes of evidence and appendices / Science and Technology Committee.

Third Report

SCIENTIFIC ADVISORY SYSTEM: SCIENTIFIC ADVICE ON CLIMATE CHANGE

Report, Proceedings of the Committee, Minutes of Evidence and Appendices

Ordered by The House of Commons *to be printed*
28 February 2001

PUBLISHED BY AUTHORITY OF THE HOUSE OF COMMONS
LONDON – THE STATIONERY OFFICE LIMITED
£14·70

HC 14

The Science and Technology Committee is appointed to examine on behalf of the House of Commons the expenditure, administration and policy of the Office of Science and Technology (and any associated public bodies). Its constitution and powers are set out in House of Commons Standing Order No. 152.

The Committee has a maximum of eleven members, of whom the quorum for any formal proceedings is three. The members of the Committee are appointed by the House and unless discharged remain on the Committee until the next dissolution of Parliament. The present membership of the Committee is as follows:[1]

Dr Michael Clark MP (*Conservative, Rayleigh*)[2]
Sir Paddy Ashdown MP (*Liberal Democrat, Yeovil*)[6]
Mrs Claire Curtis-Thomas MP (*Labour, Crosby*)[2]
Dr Ian Gibson MP (*Labour, Norwich North*)[2]
Dr Brian Iddon MP (*Labour, Bolton South East*)[5]
Mr Robert Jackson MP (*Conservative, Wantage*)[3]
Dr Lynne Jones MP (*Labour, Birmingham Selly Oak*)[2]
Dr Ashok Kumar MP (*Labour, Middlesborough South and East Cleveland*)[2]
Mr Ian Taylor MP (*Conservative, Esher and Walton*)[4]
Dr Desmond Turner MP (*Labour, Brighton Kemptown*)[2]
Dr Alan W Williams MP (*Labour, Carmarthen East and Dinefwr*)[2]

On 30 July 1997, the Committee elected Dr Michael Clark as its Chairman.

The Committee has the power to require the submission of written evidence and documents, to examine witnesses, to appoint specialist advisers, and to make Reports to the House. In the footnotes to this Report, references to oral evidence are indicated by 'Q' followed by the question number, references to the written evidence are indicated by 'Evidence' followed by a page number.

The Committee may meet at any time (except when Parliament is prorogued or dissolved) and at any place within the United Kingdom. The Committee may meet concurrently with other committees or sub-committees established under Standing Order No. 152 for the purposes of deliberating, taking evidence or considering draft reports. The Committee may meet concurrently with the House's European Scrutiny Committee (or any of its sub-committees) for the purposes of deliberating or taking evidence. The Committee may exchange documents and evidence with any of these committees, as well as with the House's Public Accounts and Deregulation Committees.

The Reports and evidence of the Committee are published by The Stationery Office by Order of the House. All publications of the Committee (including press notices) are on the Internet at www.parliament.uk/commons/selcom/s&thome.htm. A list of Reports of the Committee in the present Parliament is on page xxiv of this volume.

All correspondence should be addressed to The Clerk of the Science and Technology Committee, Committee Office, 7 Millbank, London SW1P 3JA. The telephone number for general inquiries is: 020 7219 2794; the Committee's e-mail address is: scitechcom@parliament.uk.

---

[1] Mrs Caroline Spelman MP (*Conservative, Meriden*) was appointed on 14 July 1997 and discharged on 22 June 1998.
Mr David Atkinson MP (*Conservative, Bournemouth*) was appointed on 14 July 1997 and discharged on 30 November 1998.
Mrs Jacqui Lait MP (*Conservative, Beckenham*) was appointed on 22 June 1998 and discharged on 5 July 1999.
Mr Nigel Beard MP (*Labour, Bexleyheath and Crayford*) was appointed on 14 July 1997 and discharged on 20 March 2000.
Mr Nigel Jones (*Liberal Democrat, Cheltenham*) was appointed on 14 July 1997 and discharged on 15 May 2000.

[2] Appointed on 14 July 1997.

[3] Appointed on 5 July 1999.

[4] Appointed on 30 November 1998.

[5] Appointed on 20 March 2000.

[6] Appointed on 15 May 2000.

TABLE OF CONTENTS

Page

LIST OF RECOMMENDATIONS AND CONCLUSIONS iv

REPORT

Introduction vii

Climate change viii
The scientific background viii
The political background viii

Sources of scientific advice to Government ix
The IPCC ix
The Hadley Centre x
Other sources of advice xii
Other disciplines and dissident voices xiii

The research base xiv

Policymakers' use of scientific advice xv
Scientific uncertainty and the precautionary principle xv
Intragovernmental co-ordination xvii

Conclusion xvii

LIST OF ABBREVIATIONS USED IN THE REPORT AND EVIDENCE xix

PROCEEDINGS OF THE COMMITTEE RELATING TO THE REPORT xxi

LIST OF WITNESSES xxii

LIST OF MEMORANDA INCLUDED IN THE MINUTES OF EVIDENCE xxii

LIST OF APPENDICES TO THE MINUTES OF EVIDENCE xxiii

LIST OF REPORTS xxiv

MINUTES OF EVIDENCE 1

APPENDICES TO THE MINUTES OF EVIDENCE 53

LIST OF RECOMMENDATIONS AND CONCLUSIONS

1. **It is largely because its process of assessment is, in Sir John Houghton's words, "open, transparent and rigorous" that the IPCC's reports command such general respect. (Paragraph 6)**

2. **The summaries of the IPCC's assessment reports are concise and useful documents, and present the consensus view of climate change in appropriately cautious terms. However, focusing attention on these summaries may limit the IPCC's effectiveness in communicating to policymakers the extent of the uncertainties of climate change science. (Paragraph 8)**

3. **We recommend that the Government actively promote the IPCC model in other policy areas of global significance in which there is considerable scientific uncertainty. (Paragraph 9)**

4. **We agree that it is important for the Hadley Centre to work closely with other specialist institutes, and that it should continue to concentrate on its core strengths. However, we strongly suggest that it might benefit from more in-house staff with expertise outside meteorology, including the biological sciences. (Paragraph 12)**

5. **We recommend that the results of the 10 year review of the Hadley Centre be published as soon as it is completed. (Paragraph 13)**

6. **It is important for public confidence that scientific advice to Government on climate change, as in other areas, should be *seen* to be independent and not dependent solely on the Hadley Centre. (Paragraph 14)**

7. **There must be concern whether the Hadley Centre is able to offer Government critical assessment of the IPCC reports, because it is so closely involved in the IPCC process. (Paragraph 15)**

8. **If the Tyndall Centre proves its worth, we recommend that its funding be put on a more secure and long-term footing, since climate change issues will be with us for many years yet. (Paragraph 17)**

9. **The Government must ensure that it receives advice on climate change from all relevant scientific disciplines. (Paragraph 18)**

10. **The Government must also ensure that it is aware of the views of independent scientists, who may dissent from the consensus view of climate change. (Paragraph 19)**

11. **We believe that there needs to be some rethinking of the mechanisms by which Government gets its advice. Clear and transparent channels should be available through which scientists who hold dissenting views can readily communicate their ideas to policymakers and can have confidence that they have been heard. (Paragraph 19)**

12. **We recommend that the Government establish a new independent advisory committee to advise Government on the science of climate change and on policy options. (Paragraph 20)**

13. **We recommend that the Government reconsider the adequacy of the current research programme on the biological effects of climate change, and its funding, and ensure that it is properly integrated with other climate change research. (Paragraph 25)**

14. **We are not convinced that the UK's national research programme on climate change is sufficiently coherent overall or that it has the required breadth in all areas. (Paragraph 26)**

15. **The formula used by the IPCC to communicate degrees of uncertainty could usefully be adopted in other scientific advice. (Paragraph 27)**

16. **Climate change is a prime example of an area in which the precautionary principle is being applied. Even though there is considerable uncertainty, the consequences of inaction are sufficiently serious to require action. In this case, some action is being taken to curb greenhouse gas emissions, even though it is not absolutely certain that greenhouse gases cause climate change, because the consequences of inaction for the climate may be great. (Paragraph 28)**

17. **We urge the Government to demonstrate that it is observing the precautionary principle, not just in its policy on emissions, but in responding to the threatened effects of climate change – for example, in flood prevention measures and planning policy – and in alternative transport strategies and in investing in research and development in renewable energy. (Paragraph 28)**

18. **It is most important that the Department's analysis of the changes required to reduce CO_2 emissions by 60% be published to inform the public debate on climate change. (Paragraph 29)**

19. **Policymakers in this country and abroad ought to resist the temptation to hide behind scientific uncertainty in order to avoid introducing the very great changes required to reduce greenhouse gas concentrations significantly. (Paragraph 29)**

20. **There are considerable commercial opportunities for UK science and technology, in responding, together with industry, to the challenges of climate change. (Paragraph 30)**

21. **Scientific advice on climate change and its management must be communicated effectively across both central and local Government. (Paragraph 33)**

22. **Climate change is an area in which, broadly speaking, scientific advice to Government appears to be working well. (Paragraph 34)**

23. **The research programme must anticipate the need for advice in future years and should be broad enough to address new and unforeseen issues as they arise. (Paragraph 35)**

24. **The IPCC has played a very important part in forging an international consensus on climate change, among both scientists and Governments, though it is regrettable that the USA is yet to appreciate the necessity of early action to reduce its greenhouse gas emissions. We urge the UK Government to press for international agreement on the rules for implementing the Kyoto Protocol when the negotiations are resumed in the summer of 2001. (Paragraph 36)**

25. **We believe that the IPCC model could usefully be adopted for scientific advice in other policy areas of global significance, for example on genetically modified organisms and ocean pollution. (Paragraph 37)**

THIRD REPORT

The Science and Technology Committee has agreed to the following Report:—

SCIENTIFIC ADVISORY SYSTEM: SCIENTIFIC ADVICE ON CLIMATE CHANGE

Introduction

1. As the fourth, and final, case study in our inquiry into the Scientific Advisory System we have examined the scientific advice which the Government receives on climate change.[1] We launched this case study in November 1999 with the intention of identifying:

"(A) the extent to which the Government has been advised of potential alternative explanations, how these alternatives have been assessed and what conclusions have been drawn;

(B) what critical appraisal there has been of models predicting climate change, increasing concentrations of carbon dioxide, and other potential drivers; and

(C) the degree of Government agreement with scientists in relevant specialisations regarding accepted explanations of climate change."[2]

It has not been our purpose to inquire whether or not there is global warning: we have taken as given that there is an upward trend in the temperature of the earth, and that carbon dioxide concentrations in the atmosphere are, and have been, increasing. Nor has it been our purpose to inquire into the cause of global warming, and whether, or to what extent, it is man-made. We acknowledge the work that has been done by the Environment, Transport and Regional Affairs Committee and by the Environmental Audit Committee in examining the Government's response to climate change.[3] We also acknowledge the work of our predecessor Committee on research into climate change in its inquiry into the Natural Environment Research Council in 1996-97.[4] In this Report we examine how the Government obtains scientific advice on climate change and whether it is authoritative and comprehensive. We also examine the national research programme which informs this scientific advice; and we consider how policymakers deal with scientific uncertainty.

2. During this case study we have received sixteen memoranda from a range of organisations. We have held three sessions of oral evidence. The first, on 15 March 2000, was with Sir John Houghton, former Chief Executive of the Meteorological Office and now co-Chair of Working Group I of the Intergovernmental Panel on Climate Change (IPCC). The second, on 13 December 2000, was with three climatologists: Professor David Q Bowen, Professor of Quaternary Geology at the Department of Earth Sciences, Cardiff University; Professor Alan O'Neill, Director of the Natural Environment Research Council (NERC) Centre for Global Atmospheric Modelling at the University of Reading; and Dr Simon Shackley, from the Manchester School of Management at the University of Manchester Institute of Science and Technology (UMIST), and also a programme manager in the new Tyndall Centre. The third, on 20 December 2000, was with the Minister of the Environment, the Rt Hon Michael Meacher MP; Dr David Fisk, Chief Scientist at the Department of the Environment, Transport and the Regions

---

[1] The Reports on the three earlier case studies were: First Report, Session 1998-99, *Scientific Advisory System: Genetically Modified Foods*, HC 286; Third Report, Session 1998-89, *Scientific Advisory System: Mobile Phones and Health*, HC 489; Third Report, Session 1999-2000, *Scientific Advisory System: Diabetes and Driving Licences*, HC 206.

[2] Press release, No. 1 of Session 1999-2000, 22 November 1999.

[3] See Fifth Report of the Environment, Transport and Regional Affairs Committee, Session 1999-2000, *UK Climate Change Programme*, HC194; Fourth Report of the Environmental Audit Committee, Session 1997-98, *Climate Change: UK Emission Reduction Targets and Audit Arrangements*, HC 899; Second Report of the Environmental Audit Committee, Session 1998-99, *Climate Change: Government Response and Follow-up*, HC 88.

[4] See Third Report of the Science and Technology Committee, Session 1996-97, *The Natural Environment Research Council and Research into Climate Change*, HC 81; and Government Response (Second Special Report, Session 1997-98, HC 306).

(DETR); and Mr David Warrilow, Head of Science Policy in the DETR's Global Atmosphere Division. We are grateful to all those who provided evidence, and to our four specialist advisers: Professor Derek Burke, formerly Vice-Chancellor of the University of East Anglia; Professor Michael Elves, formerly Director of the Office of Scientific and Educational Affairs, Glaxo Wellcome plc; Professor Peter Liss, Professor of Environmental Sciences at the University of East Anglia; and Professor John Pyle, Director of the Centre for Atmospheric Science, Cambridge University.

Climate change

3. Climate change – which, following IPCC usage, we take to mean any change in climate over time, whether due to natural variability or as a result of human activity – is a major issue confronting policy makers, yet it is an area of considerable scientific uncertainty. It gives rise to a range of policy questions, including: what position the UK should take in international negotiations on emission reductions, and how it should respond to the international agreements reached; what fiscal measures might most effectively be taken to discourage emissions and to encourage the use of, and investment in, alternative, renewable, energy; how it should manage the effects of severe weather and rising sea level, in terms of flood protection and coastal defence; how transport policy might be affected by emission reduction targets; and how agriculture should respond to changing climate. In all these areas Government requires scientific advice.

THE SCIENTIFIC BACKGROUND

4. It is generally agreed that global warming is taking place. (The global average surface temperature increased over the 20th Century by around 0.6° C.[5]) There is some disagreement, however, about the extent to which this global warming is anthropogenic (man-made). There is agreement that there are increasing concentrations of "greenhouse gases"– largely carbon dioxide, nitrous oxide, methane and chlorofluorocarbons (CFCs) – in the Earth's atmosphere, but there is uncertainty about the extent to which the "greenhouse effect" (by which the increasing concentrations of these gases trap solar radiation, leading to global warming) accounts for the observed temperature change. There is agreement that the climate can change naturally (through variation in solar output, or the release of volcanic dust, for example), and that there have been marked natural climate changes in the past, but there is uncertainty regarding the extent to which the recent increase in temperatures might be caused by such natural factors. While climate models are becoming increasingly sophisticated and accurate at prediction, there is still uncertainty about the "feedback" effects of clouds, of water vapour, of ocean circulation and of forests. There is uncertainty about the consequences of climate change, and about the local impacts of the predicted increase in sea level and in more extreme weather. There is agreement that polar ice is melting, but uncertainty as to how much, as well as to the possible future effect of this on ocean currents. There is uncertainty too about the effectiveness of possible mitigation strategies: about the impact of "carbon sinks" in sequestering carbon from the atmosphere, and in retaining it; and about the speed with which fuel emission reductions would impact on greenhouse gas concentrations.

THE POLITICAL BACKGROUND

5. Climate change is a global issue which needs to be addressed by international agreement. International negotiations, in which the UK plays a leading role, have been proceeding since the 1980s. In 1988 the World Meteorological Organisation and the United Nations Environment Programme jointly set up the Intergovernmental Panel on Climate Change (IPCC) in order to provide authoritative scientific assessment of the evidence for human-induced climate change.[6] The IPCC completed its First Assessment Report in 1990, and this contributed to the

---

[5] Evidence, p 74, paragraph 3.1. IPCC's Third Assessment Report suggests 0.6 ± 0.2° C.

[6] Evidence, p 1, paragraph 1.

negotiations which led to the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) at the Earth Summit in Rio de Janeiro in June 1992. The IPCC completed its Second Assessment Report in 1995, concluding that "The balance of evidence suggests a discernible human influence on global climate".[7] This was a key input to the negotiations which led to the adoption of the Kyoto Protocol to the Framework Convention on Climate Change at the Third Conference of Parties meeting in Kyoto in December 1997, which agreed targets for reduction of emissions of greenhouse gases by developed countries.[8] The Sixth Conference of Parties (COP6)[9] met at the Hague in November 2000, and failed to gain agreement on how to implement the reductions agreed at Kyoto. The negotiations are expected to reconvene in Bonn in May 2001; and COP7 will meet in Marrakech in October 2001. The IPCC's Third Assessment Report is to be released later this year: the scientific assessment report of the IPCC's Working Group I (WG I) was accepted at a meeting of IPCC member governments in Shanghai in January 2001. The "Summary for Policymakers" approved at that meeting concludes that "most of the warming observed over the last 50 years is attributable to human activities".[10]

Sources of scientific advice to Government

THE IPCC

6. According to the DETR's memorandum, the principal source of scientific advice to Government on climate change is the reports of the IPCC.[11] The IPCC works through three Working Groups. Working Group I assesses the science of climate change; Working Group II assesses the socio-economic and natural impacts of climate change and the options for adapting to it; and Working Group III assesses the options for limiting greenhouse gas emissions and otherwise mitigating climate change. WG I involves many hundreds of climatologists from around the world, covering a wide range of disciplines and a variety of opinions. WG I's reports are very lengthy documents, including authored chapters, a technical summary and a shorter summary for policymakers. The reports are subject to extended peer review, and to very widespread scrutiny before publication by scientists and by Governments.[12] In Dr Shackley's words, "the Policymakers' Summary and Technical Summary of the IPCC reports are amongst the most scrutinised scientific documents ever produced".[13] **It is largely because its process of assessment is, in Sir John Houghton's words, "open, transparent and rigorous"[14] that the IPCC's reports command such general respect.**

7. It is significant that the IPCC is an *intergovernmental* body. Before its reports are published they are scrutinised in detail by representatives of the member governments as well as scientists. This has the advantage that governments accept the conclusions of the published reports, and in a sense take "ownership" of them. It also means that governments – the UK Government included – are unusually close to the latest and most authoritative scientific opinion world-wide. On the other hand, the involvement of governments makes the IPCC a highly political organisation. While Sir John Houghton assured us that the IPCC stuck "very firmly to a presentation of the science, not the political interpretation of that science"[15], Dr Shackley's description of the WG I plenary meeting in Madrid in 1995 indicates that the IPCC's negotiations have a distinctly political quality.[16] There must be a danger that, in bringing together such diverse and conflicting interests to reach a consensus, the "lowest common

---

[7] IPCC Second Assessment Report, *Climate Change 1995*. See Evidence, p 39, paragraph 24.

[8] It was agreed that the industrialised countries would reduce their total greenhouse gas emissions by 5.2% from 1990 levels by the period 2008-2012.

[9] COP1 met in Berlin in March 1995. COP2 met in Geneva in July 1996. COP4 met in Buenos Aires in November 1998; COP5 in Bonn in October 1999. For details, see www.unfccc.de .

[10] See www.ipcc.ch .

[11] Evidence, p 37, paragraph 9.

[12] For detail of IPCC's working practice, see Evidence, pp 3-7.

[13] Evidence, p 24, paragraph 9.

[14] Evidence, p 6.

[15] Q 23.

[16] Evidence, p 24, paragraph 8.

denominator" view will prevail. It is remarkable – and to the great credit of the scientists involved – that the IPCC's reports are incisive.

8. One advantage of the IPCC's political framework is that it ensures that the prevailing anthropogenic view of climate change is thoroughly tested, and that alternative views are properly aired. For example, oil-producing members of the IPCC have a clear interest in ensuring that the view that fossil fuels are to blame for climate change is subject to close scrutiny, that uncertainty is exposed and that alternative natural causes are properly explored. While the majority of scientists at the IPCC take the view that climate change is at least partly man-made, it includes some who hold dissenting views. For example, Professor Richard Lindzen from the Massachusetts Institute of Technology (who is a well known sceptical voice on the extent of climate change as predicted from models) is one of the lead authors of the Third Assessment Report.[17] The IPCC's full reports reflect these differences of views, though the policymakers' summary gives only the consensus position. Dr Shackley told us that "within the full report there is a whole wealth of viewpoints and uncertainties that do not always find themselves in the policymakers' summary".[18] But, of course, most policymakers will read no further than the policymakers' summary. The Minister told us that, while he had a copy of the full Second Assessment Report, and had dipped into it, his reading was largely confined to the summaries, because of the pressure of time.[19] **The summaries of the IPCC's assessment reports are concise and useful documents, and present the consensus view of climate change in appropriately cautious terms. However, focusing attention on these summaries may limit the IPCC's effectiveness in communicating to policymakers the extent of the uncertainties of climate change science.**

9. That said, there is no doubt that the IPCC is generally held in very high regard. It has been suggested that the IPCC could be a model for scientific advice on other issues of complexity and global concern. For example, at the OECD Edinburgh Conference on the scientific and health aspects of genetically modified foods in February 2000, it was proposed that the IPCC model could be used, in an adapted form, to build a scientific consensus on genetically modified (GM) organisms.[20] The Minister told us that he would be happy to promote the IPCC model internationally, though in his view there was much more scientific controversy about GM organisms than there was about climate change.[21] Another area for building international scientific consensus, and one requiring action world-wide, is ocean pollution. **We recommend that the Government actively promote the IPCC model in other policy areas of global significance in which there is considerable scientific uncertainty.**

THE HADLEY CENTRE

10. Between IPCC assessments, the Government appears to rely for advice on climate change predominantly on the Hadley Centre of the Meteorological Office.[22] The Hadley Centre for Climate Prediction and Research was set up in 1990, adjacent to, and a part of, the Met Office at Bracknell, to provide Government with up-to-date advice on all aspects of climate change, particularly in order to inform the UNFCCC negotiations.[23] The Hadley Centre's work is based on the use of computer models of the atmosphere, ocean, biosphere, cryosphere and land surface to predict climate change.

---

[17] Q 11.

[18] Q 64.

[19] Q 140.

[20] See Chairman's Report of the OECD Edinburgh Conference on the scientific and health aspects of genetically modified foods, OECD 2000.

[21] Q 142.

[22] Q 75.

[23] Evidence, p 37, paragraph 13; p 73, paragraph 1. The Hadley Centre is named after George Hadley, an 18th Century scientist who proposed a simple model of the Earth's atmospheric circulation.

11. While global climate models[24] are generally agreed to be an essential tool in gaining understanding of climate change, some scientists are sceptical of the ability of models accurately to predict climate change.[25] Sir John Houghton acknowledged that "because of the complexities of the climate system, models are inadequate in various respects and have to be carefully appraised".[26] Global climate models, which incorporate information about oceanic as well as atmospheric circulations, are becoming increasingly sophisticated. They are increasingly effective in simulating feedback mechanisms, in reproducing past climates, and in allowing local effects to be identified. The DETR commissions independent validation of the Hadley Centre's models by the Climatic Research Unit at the University of East Anglia.[27] The Hadley Centre's latest global climate model was ranked best overall in simulation of the current climate in a recent international comparison by the Coupled Model Intercomparison Project.[28]

12. Some of those providing evidence to us suggest that, while the Hadley Centre is very expert in climate modelling and in the physics and mathematics of climate change, it lacks expertise in other disciplines, notably the biological sciences.[29] They suggest that it is ill-equipped, therefore, to advise the Government on many aspects of climate change, which are of considerable importance to policymakers (for example, on the performance of carbon sinks, which was a major focus of the COP6 negotiations last November). The DETR acknowledges that the Hadley Centre's in-house expertise is largely in maths and physics, though it has a few staff with degrees in environmental science, geography and related disciplines. The DETR's view is that it is more effective for the Hadley Centre to work closely with biologists and ecologists at other institutes (notably the NERC Centre for Ecology and Hydrology).[30] Dr Fisk argued that "if we had simply made the Hadley Centre the centre of everything it would become unstable and not open to the broader challenge of the scientific community".[31] **We agree that it is important for the Hadley Centre to work closely with other specialist institutes, and that it should continue to concentrate on its core strengths. However, we strongly suggest that it might benefit from more in-house staff with expertise outside meteorology, including the biological sciences.**

13. Some of the evidence we have received suggests that the Government is over-reliant on the Hadley Centre, and therefore on climate models, and pays insufficient attention to alternative sources of advice.[32] Dr Shackley estimated that the Government got perhaps 90% of its advice from the Hadley Centre.[33] Critics suggest that the Hadley Centre is insufficiently independent, given that it is directly government-funded[34] and part of a government agency. The Minister, not surprisingly, did not consider that the Government was "unduly dependent" on the Hadley Centre nor that there was "an over-cosy relationship" between the Hadley Centre and Government.[35] He pointed out that all the Hadley Centre's research is published and open to external scrutiny which included a rigorous peer review process.[36] The work of the Hadley Centre is monitored by an independent Science Review Group of UK experts, and its models are subjected to independent validation by the Climatic Research Unit at the University of East Anglia. The Hadley Centre was subject to a major review five years after it was established, and is currently undergoing a ten year review, which includes a review of its science by a panel of international

---

[24] Most of the models used now for global climate prediction are fully coupled (ocean/atmosphere) general circulation models (GCMs). Although simpler models may be used for more regional/local studies, the trend is to use the ever increasing power of computers to embed finer scale models within GCMs.

[25] Eg Evidence, pp 56, 67-68; Q 113.

[26] Evidence, p 2, paragraph 7.

[27] Evidence, p 38, paragraph 19. See also Evidence, p 64, paragraph 8.

[28] Evidence, p 38, paragraph 18; p 78, paragraph 6.14. For details of the CMIP, see www-pcmdi.llnl.gov/cmip .

[29] Qq 99, 105.

[30] Q 132. Evidence, p 51.

[31] Q 134.

[32] Eg Evidence, pp 22-23, paragraphs 2-5; p 56, paragraph IV.

[33] Q 75.

[34] The Hadley Centre has an annual income of £11m: £8 m from DETR; £3 million from MoD; and £0.3 million from the European Commission. See Evidence, p 73, paragraph 1.1.

[35] Qq 128, 130.

[36] Qq 129, 130.

experts, as well as a review of its finance and management.[37] **We recommend that the results of the 10 year review of the Hadley Centre be published as soon as it is completed.**

14. The Hadley Centre's closeness to Government has advantages, of which perhaps the most obvious is that communication of scientific advice to policymakers is swift and effective. It is at least partly because of the unusually close relationship between DETR policymakers and scientists at the Hadley Centre that the UK Government has been at the forefront of international action on climate change. We have no evidence to suggest that the Hadley Centre's advice is compromised by its closeness to Government, or that it acts in any way differently from an independent research institution. Nevertheless, **it is important for public confidence that scientific advice to Government on climate change, as in other areas, should be *seen* to be independent and not dependent solely on the Hadley Centre.**

15. The Hadley Centre is not just close to Government; it is also very close to the IPCC. The WG I's Technical Support Group (effectively its secretariat) is located at the Hadley Centre; and, further, the WG I is co-chaired by Sir John Houghton, chief executive of the Met Office from 1983 to1988. In many ways this close connection is admirable, and is an indication of the high regard in which the Hadley Centre is held internationally. Yet, **there must be concern whether the Hadley Centre is able to offer Government critical assessment of the IPCC reports, because it is so closely involved in the IPCC process.**

OTHER SOURCES OF ADVICE

16. The DETR points out that on climate change it is not just advised by the Hadley Centre. On the impacts of climate change, it is advised by the Climatic Research Unit at the University of East Anglia, by the Environmental Change Institute at Oxford University, and by NERC's Centre for Ecology and Hydrology.[38] It is also advised by NERC's Southampton Oceanography Centre.[39] Indeed, Dr Fisk maintained that "one of the strengths of the Department's programme on climate change is that we have not focused all our funding on the Hadley Centre".[40] We welcome this diversity of advice. As the Minister stated, "to rely exclusively on one body would be unwise in an area which is so multifaceted".[41]

17. A new source of advice on the impact of climate change is the Tyndall Centre for Climate Change Research which opened in November 2000.[42] The Centre is based at the University of East Anglia in Norwich with regional offices at UMIST in Manchester and at the University of Southampton. It brings together climate scientists, economists, social scientists and engineers from nine higher education and research institutions, to assess the implications of climate change and to develop sustainable solutions.[43] It was established by NERC, together with the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC), with £10 million funding over five years.[44] We note that one of the requirements on the Centre will be to create mechanisms for turning its research findings into scientific advice to government.[45] **If the Tyndall Centre proves its worth, we recommend that its funding be put on a more secure and long-term footing, since climate change issues will be with us for many years yet.**

---

[37] Evidence, p 38, paragraph 16.
[38] Evidence, p 37, paragraph 9. Q 35.
[39] Q 119.
[40] Q 134.
[41] Q 123.
[42] Qq 122-124. The Tyndall Centre is named after John Tyndall, the 19th Century scientist who was one of the first to identify the natural greenhouse effect.
[43] For details, see www.tyndall.uea.ac.uk .
[44] Evidence, p 70, paragraph 7; Q 124.
[45] Evidence, p 70, paragraph 7.

OTHER DISCIPLINES AND DISSIDENT VOICES

18. A key question in our inquiry has been whether the Government has been fully advised of potential alternative explanations of climate change; and specifically, whether it is sufficiently aware of dissident voices who maintain that the uncertainties are too great to conclude that climate change is to a significant extent man-made. The Minister was confident that Government was obtaining a full range of advice: "this is an area where the quality and range of advice which I am getting is extremely high. I do not have suspicions about what I am not being told, as I do occasionally in other areas."[46] On the other hand, there appears to be a sense among some scientists, particularly geologists and biologists, that they are excluded from what might be termed the Hadley Centre and IPCC coterie who advise the Government. The Geological Society of London questioned the extent to which Government seeks the views of a broad range of scientists in addition to the advice given by its appointed advisers and consultants.[47] **The Government must ensure that it receives advice on climate change from all relevant scientific disciplines.**

19. **The Government must also ensure that it is aware of the views of independent scientists, who may dissent from the consensus view of climate change.** While we have no wish to throw doubt on the strong consensus that climate change is man-made, we believe that, in Dr Shackley's words, "it is vital that alternative explanations are constantly scrutinised and encouraged into the debate".[48] Dissidents sometimes turn out to be right in at least some of what they say. Professor Bowen, though cautious in his words, strongly conveyed his belief that dissenting views were not being sufficiently heard by Government, or by the IPCC.[49] As we have seen, the range of views explored in the full reports of the IPCC are not reflected in the policymakers' summaries. **We believe that there needs to be some rethinking of the mechanisms by which Government gets its advice. Clear and transparent channels should be available through which scientists who hold dissenting views can readily communicate their ideas to policymakers and can have confidence that they have been heard.**

20. A way for the Government to ensure that it is aware of all currents of advice on climate change – and to demonstrate that it is not overly dependent on the Hadley Centre – would be to create an advisory committee of eminent scientists drawn from a wide range of interests and disciplines. In general, we believe that there are too many advisory committees in existence, and that more should be created only if there is a clear need and obvious benefit. In the case of climate change, we believe that such a committee would be justified. It should be made clear in its terms of reference that its role is not to duplicate the work of the IPCC, but to advise Government on UK policy on climate change. We envisage that the new committee should have a different role from the former Inter-Agency Committee on Global Environmental Change or its replacement, the Global Environmental Change Committee, which we discuss in paragraph 23 below, being advisory rather than co-ordinating in purpose (though by bringing scientists of different disciplines together, it would clearly assist co-ordination). It could usefully be asked to comment on policy options as well as to advise on the science. It should be clearly independent of Government, and be chaired by an academic scientist. In order to underline this independence, and to build on the work that the Royal Society is already doing in this field, it might be that the new committee could be jointly established by Government and by the Royal Society, perhaps along the US National Academy of Science/National Research Council model. Accordingly, **we recommend that the Government establish a new independent advisory committee to advise Government on the science of climate change and on policy options.**

---

[46] Q 150.

[47] Evidence, p 57, paragraph 5.

[48] Evidence, p 24, paragraph 10.

[49] Q 83. Also Qq 64, 84, 113.

The research base

21. As the Institute of Biology states, "scientific advice can change as more questions are asked and detailed information provided by researchers".[50] It is the role of the Research Councils to ensure that the UK science base is robust enough to be able to answer questions from policymakers on issues of topical importance. NERC has the lead role in promoting climate research, undertaking or funding a wide range of programmes studying past and natural climate change, as well as anthropogenic climate change and its impacts.[51]. The ESRC has funded two major programmes (the Global Environmental Change (GEC) Programme based at the University of Sussex, and the Centre for Social and Economic Research on the Global Environment (CSERGE) at the University of East Anglia and University College London) as well as individual research grants.[52] The EPSRC is involved with NERC and ESRC in funding the new Tyndall Centre, as part of its £30 million a year commitment to sustainable development. The Biotechnology and Biological Sciences Research Council (BBSRC) has funded research, focusing on the effects of climate change on microbes, plants and animals, and its impact on agriculture.[53] According to BBSRC's memorandum, the Research Councils seek to co-ordinate their work through a Cross-Council Group on Climate Change (CCGCC), but we understand that it was set up in 1998 and has not met since 1999.[54] As Sir John Houghton told us, "putting ... things together into a coherent and sensible national research programme is still a difficulty, because different subjects are addressed in different ways, by different Research Councils".[55] There is also concern that the implications of research findings may not always be communicated effectively to policymakers.[56] The recently established Royal Society Global Environmental Research Committee has made a promising start in representing the views of the academic community and in indicating research directions which need to be pursued.

22. In addition to the research supported by the Research Councils, in their own centres and at universities, Government Departments commission research directly. For example, the DETR funds the UK Climate Impacts Programme, based at the Environmental Change Institute at Oxford University.[57] The Minister suggested that the Research Councils dealt with the "strategic science", while the DETR dealt with "policy-driven policy-relevant questions"[58], but the division of responsibility is not entirely clear. There is some concern that Government Departments pursue independent research agenda, without sufficient co-ordination with other Departments or the Research Councils. According to the BBSRC, "Government Departments tend to commission their own studies and it is unclear how much cross-fertilisation there is".[59]

23. This concern has been heightened by the winding up of the Inter-Agency Committee on Global Environmental Change (IACGEC), which until recently was responsible for "high level co-ordination of UK research on climate change and other global environmental issues".[60] The IACGEC, which was chaired by Professor Sir Richard Southwood, Professor of Zoology at Oxford University, has been replaced by the Global Environmental Change Committee, chaired by Dr Fisk, the Chief Scientist at the DETR, apparently on the advice of the Chief Scientific Adviser.[61] Dr Fisk told us that it was thought appropriate to replace IACGEC with something less bureaucratic and more directed to organising coherence with policy outcomes.[62] We can see no reason for more than one committee co-ordinating research on climate change, and suggest that the new Global Environmental Change Committee be given a chance to prove itself in this role. We envisage that this co-ordinating committee would have an administrative role,

---

[50] Evidence, p 67, paragraph 8.
[51] See Evidence, pp 69-72.
[52] Evidence, pp 84-89.
[53] Evidence, pp 60-61.
[54] Evidence, p 61, paragraphs 12 and 14.
[55] Q 10.
[56] Evidence, p 54, paragraph 5.
[57] Evidence, p 41, paragraph 42.
[58] Q 155.
[59] Evidence, p 63, paragraph 29.
[60] Evidence, p 36, paragraph 2.
[61] Q 156.
[62] Q 157.

overseeing the co-ordination of research and research funding, quite different from the advisory role of the independent committee we recommend in paragraph 20 above.

24. Research on climate change is, of course, being carried out world-wide. The UK is a major contributor to a number of international research activities within the World Climate Research Programme and the International Geosphere-Biosphere Programme.[63] Co-ordination of international research in this area is clearly vital, to ensure both cost-effectiveness and cross-fertilisation of ideas. The Research Councils co-operate internationally through the International Group of Funding Agencies.[64] The IPCC process plays a useful part in ensuring that scientists are aware of work carried out in other countries.

25. Witnesses have suggested that there are some areas of importance to climate change which are at present under-researched. The Institute of Biology argues that research on ecosystem function, and on the response of ecosystems to environmental changes, has been neglected; and, in particular, that more research is needed on the way carbon is sequestered.[65] The Institution of Professionals, Managers and Specialists (IPMS) suggests that there are areas of work related to climate change which are at present insufficiently researched and funded by government. They cite, as an example of this, the impact of climate change on the transmission of disease among farm animals and pets by insects.[66] **We recommend that the Government reconsider the adequacy of the current research programme on the biological effects of climate change, and its funding, and ensure that it is properly integrated with other climate change research.**

26. The Minister was confident that the UK "had one of the most effective research programmes on climate change anywhere in the world".[67] We share this confidence, though we believe it could be more effective still. **We are not convinced that the UK's national research programme on climate change is sufficiently coherent overall or that it has the required breadth in all areas.** The research programme must do more than meet policymakers' current needs for information: it must try to anticipate the advice required in future years.

Policymakers' use of scientific advice

SCIENTIFIC UNCERTAINTY AND THE PRECAUTIONARY PRINCIPLE

27. Climate change is yet another area where policymakers have to deal with considerable uncertainty in scientific advice. The science of climate change is in many ways uncertain, though understanding is growing rapidly. Policymakers prefer certainty – as the Minister told us, "when you have to deal with the Treasury, ... it is much better to speak in terms of certainties than in terms of weighted probabilities"[68] – but, in this area, policymakers appear to have accepted that there is an unavoidable element of uncertainty. There does not appear to have been pressure on scientific advisers to suppress uncertainty or divergent views, although – as we have seen – there is some concern that scientists of dissenting views are not heard sufficiently. The IPCC has developed a clear formula for communicating degrees of uncertainty in its assessments. In its summaries, it uses "virtually certain " to denote a greater than 99% chance that a result is true; "very likely" to denote a 90–99% chance; "likely" to denote a 66–90% chance; "medium likelihood" to denote a 33–60% chance; "unlikely" to denote a 10–33% chance; "very unlikely" to denote a 1–10% chance; and "exceptionally unlikely" to denote a less than 1% chance. For example, in the Third Assessment Report of Working Group I, the IPCC states that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations" and that "it is *very likely* that the 20th century

---

[63] Evidence, p 40, paragraph 34.
[64] Evidence, p 61, paragraph 14.
[65] Evidence, p 67, paragraph 7.
[66] Evidence, p 54, paragraph 4.
[67] Q 155.
[68] Q 148. See also Q 92.

warming has contributed significantly to the observed sea level rise".[69] **The formula used by the IPCC to communicate degrees of uncertainty could usefully be adopted in other scientific advice.**

28. **Climate change is a prime example of an area in which the precautionary principle is being applied. Even though there is considerable uncertainty, the consequences of inaction are sufficiently serious to require action. In this case, some action is being taken to curb greenhouse gas emissions, even though it is not absolutely certain that greenhouse gases cause climate change, because the consequences of inaction for the climate may be great.** And it appears that the precautionary principle is being applied by scientists as well as policymakers. As Dr Shackley told us, "there is, as well as a common understanding of the science, also an element of a precautionary ethic in the work of, say, the IPCC in the sense that ... we should be erring on the side of caution when it comes to issues like climate change".[70] A principle of proportionality can also be identified: the more severe the implications, the more necessary that we respond, despite the uncertainty. **We urge the Government to demonstrate that it is observing the precautionary principle, not just in its policy on emissions, but in responding to the threatened effects of climate change – for example, in flood prevention measures and planning policy – and in alternative transport strategies and in investing in research and development in renewable energy.**

29. Climate change is also an example of the limits of the precautionary principle. The developed countries agreed at Kyoto to a 5.2% reduction in greenhouse gas emissions, but it remains to be seen whether they will be prepared to accept the 60, 70 or even 90% reductions which are being suggested to be necessary to have a significant impact on greenhouse gas concentrations, while allowing for industrial growth by the developing countries. As the Minister acknowledged, the implications of emission reductions of that size are "absolutely mind-blowing".[71] The Minister told us that he had asked the Department to produce an outline of what might be involved with a reduction of 60% in CO_2 in the UK or any industrialised country; and that he suspected that "it will be sufficiently worrisome that the Department will be extremely unwilling to publish it". Even if the Minister's comment was lighthearted, this indicates the severity of the action required. **It is most important that the Department's analysis of the changes required to reduce CO_2 emissions by 60% be published to inform the public debate on climate change.** In reality, the need for action is balanced against the political, economic and social consequences of action – particularly where that need for action is uncertain. The more unpalatable the action required, the less likely it is that the precautionary principle will be applied. **Policymakers in this country and abroad ought to resist the temptation to hide behind scientific uncertainty in order to avoid introducing the very great changes required to reduce greenhouse gas concentrations significantly.**

30. On the more positive side, there are potentially large economic benefits for those who anticipate global action on climate change by developing technologies and products for reducing greenhouse gas emissions or for exploiting alternative sources of energy. In our forthcoming inquiry into Wave and Tidal Energy we intend to examine the potential of one form of renewable energy. **There are considerable commercial opportunities for UK science and technology, in responding, together with industry, to the challenges of climate change.**

31. One of the uncertainties of climate change is the possibility of rare but cataclysmic natural events, such as a major volcanic eruption, which could have a dramatic effect on climate, more than outweighing anthropogenic factors contributing to global warning. Evidence from the Geological Society of London expressed concern about the extent to which the Government had addressed the implications of rapid short term changes in weather and climate caused by large volcanic eruptions.[72] Volcanic eruptions have had a significant effect on the weather in the past,

---

[69] Third Assessment Report: Summary for Policymakers.

[70] Q 84.

[71] Q 152.

[72] Evidence, p 56, paragraph III.

reducing temperatures worldwide for a number of years.[73] It is hard to see how Governments could effectively plan for such unpredictable events, though it is clearly a possibility of which they should be aware. We welcome the Minister's assurance that the arrangements for dealing with natural disasters are under review.[74]

INTRAGOVERNMENTAL CO-ORDINATION

32. Though the DETR has lead responsibility in the Government's response to climate change, issues arising from climate change involve many Government Departments. The Ministry of Agriculture, Fisheries and Food is involved in assessing the implications of climate change for agriculture and coastal defence. The Department of Trade and Industry is involved in managing energy policy. The Treasury is involved in determining fiscal policies to discourage greenhouse emissions. The Office of Science and Technology is involved through its funding of scientific research through the Research Councils. The DETR's memorandum states that climate change policy is co-ordinated through the Inter-Departmental Liaison Group, though its exact role is unclear to us.[75] Effective interdepartmental co-ordination on climate change is essential.

33. Managing the effects of climate change – flooding and coastal erosion, for example – also involves local government, which also requires clear and authoritative scientific advice. The Institute of Biology warned that "some local government administrations appear less aware of scientific advice relating to climate change and this is likely to result in costs on society".[76] **Scientific advice on climate change and its management must be communicated effectively across both central and local Government.**

Conclusion

34. **Climate change is an area in which, broadly speaking, scientific advice to Government appears to be working well.** Scientific advice is well integrated in policy making, largely because of the very close links which exist between the DETR and the Hadley Centre. Through the reports of the IPCC, and because of the close links between the Hadley Centre and the IPCC, the Government is well informed about the latest, and most authoritative, scientific opinion from across the world. The way in which the IPCC operates ensures that the advice it gives to Governments is validated by extensive peer review. It is partly because of the openness of the IPCC process that – in marked contrast to other areas of scientific advice – the advice which the Government gets on climate change is not a matter of public concern or suspicion.

35. However, there is some concern that – as in other areas – Government gives ear only to the scientific establishment or consensus view, and that it is not sufficiently open to advice from scientists of dissenting opinion. There are concerns that it relies overly on the Hadley Centre and on its climate models, and is less open to advice from those working in other fields, notably in study of the palaeoclimate. While the full reports of the IPCC incorporate the views of scientists of all opinions, the policymakers' summaries reflect the consensus view that human activities are affecting the climate. It is important that the Government should hear also from those respected scientists who are sceptical to varying degrees of the anthropogenic nature of climate change. There are also concerns about the coherence and comprehensiveness of the national research programme on climate change, and particularly about the availability of advice on the biological effects. **The research programme must anticipate the need for advice in future years and should be broad enough to address new and unforeseen issues as they arise.**

36. It is at least partly because of the close links between the DETR and the Hadley Centre that the UK Government was one of the first in the world to recognise the threat of climate change and to press for international action to address it. Climate change is an area where

---

[73] Evidence, p 59, paragraphs 20-25; Q 114.

[74] Q 159.

[75] Evidence, p 41, paragraph 41.

[76] Evidence, p 66, paragraph 2 (v); p 69, paragraph 21.

unilateral action by single countries is of limited value: international agreement is vital. **The IPCC has played a very important part in forging an international consensus on climate change, among both scientists and Governments, though it is regrettable that the USA is yet to appreciate the necessity of early action to reduce its greenhouse gas emissions. We urge the UK Government to press for international agreement on the rules for implementing the Kyoto Protocol when the negotiations are resumed in the summer of 2001.**

37. **We believe that the IPCC model could usefully be adopted for scientific advice in other policy areas of global significance, for example on genetically modified organisms and ocean pollution.**

LIST OF ABBREVIATIONS USED IN THE REPORT AND EVIDENCE

AMIP	Atmospheric Model Intercomparison Project
BAGEC	Biological Adaptation to Global Environmental Change
BAS	British Antarctic Survey
BBSRC	Biotechnology and Biological Sciences Research Council
CCGCC	Cross-Council Group on Climate Change
CCMS	Centre for Coastal and Marine Sciences
CEH	Centre for Ecology and Hydrology
CFC	Chlorofluorocarbon
CMIP	Coupled Model Intercomparison Project
COP	Conference of Parties
CRU	Climatic Research Unit
CSERGE	Centre for Social and Economic Research on the Global Environment
DETR	Department of the Environment, Transport and the Regions
DfID	Department for International Development
DoH	Department of Health
DTI	Department of Trade and Industry
ECN	Environmental Change Network
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
FAO	Food and Agriculture Organisation
FCCC	Framework Convention on Climate Change
FCO	Foreign and Commonwealth Office
GCM	General Circulation Model
GEC	Global Environmental Change (Programme)
GM	Genetically Modified
HRI	Horticulture Research International
IACGEC	Inter-Agency Committee on Global Environmental Change
IACR	Institute of Arable Crop Research

ICAO	International Civil Aviation Organisation
IGER	Institute of Grassland and Environmental Research
IPCC	Intergovernmental Panel on Climate Change
IPMS	Institution of Professionals, Managers and Specialists
ITE	Institute for Terrestrial Ecology
JNCC	Joint Nature Conservation Committee
MAFF	Ministry of Agriculture, Fisheries and Food
MoD	Ministry of Defence
MRC	Medical Research Council
NASA	National Aeronautics and Space Administration
NCC	Nature Conservancy Council
NERC	Natural Environment Research Council
NGO	Non-Governmental Organisation
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
SAR	Second Assessment Report (of the IPCC)
SOC	Southampton Oceanography Centre
SPRU	Science Policy Research Unit
SRG	Science Review Group
TAR	Third Assessment Report (of the IPCC)
TSU	Technical Support Unit
UEA	University of East Anglia
UMIST	University of Manchester Institute of Science and Technology
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
WG	Working Group (of the IPCC)
WMO	World Meteorological Organisation
yBP	years before present

PROCEEDINGS OF THE COMMITTEE RELATING TO THE REPORT

WEDNESDAY 28 FEBRUARY 2001

Members present:

Dr Michael Clark, in the Chair

Dr Ian Gibson	Dr Lynne Jones
Dr Brian Iddon	Dr Desmond Turner

The Committee deliberated.

Draft Report (Scientific Advisory System: Scientific Advice on Climate Change), proposed by the Chairman, brought up and read the first time.

Ordered, That the draft Report be read a second time, paragraph by paragraph.

Paragraphs 1 to 37 read and agreed to.

Resolved, That the Report be the Third Report of the Committee to the House.

Ordered, That the Chairman do make the Report to the House.

Several papers were ordered to be appended to the Minutes of Evidence

Ordered, That the Appendices to the Minutes of Evidence taken before the Committee be reported to the House.—(*The Chairman.*)

[Adjourned till Wednesday 7 March at a quarter to Six o'clock.

LIST OF WITNESSES

Wednesday 15 March 2000

Sir John Houghton CBE 7

[This was published as HC 285-i of Session 1999–2000]

Wednesday 13 December 2000

Professor David Q Bowen, Professor Alan O'Neill and Dr Simon Shackley 26

Wednesday 20 December 2000

DEPARTMENT OF THE ENVIRONMENT, TRANSPORT AND THE REGIONS

Rt Hon Michael Meacher MP, Dr David Fisk and Mr David Warrilow 42

LIST OF MEMORANDA INCLUDED IN THE MINUTES OF EVIDENCE

1. Sir John Houghton CBE 1
2. Professor David Q Bowen, Cardiff University 17
3. Professor Alan O'Neill, Natural Environment Research Council 21
4. Dr Simon Shackley, Manchester School of Management, University of Manchester Institute of Science and Technology 22
5. Department of the Environment, Transport and the Regions 36, 51

LIST OF APPENDICES TO THE MINUTES OF EVIDENCE

Memoranda from: *Page*

1. RJB Mining (UK) Ltd. 53
2. Institution of Professionals, Managers and Specialists 53
3. The Geological Society of London 54
4. Biotechnology and Biological Sciences Research Council 60
5. Climatic Research Unit, University of East Anglia 63
6. Institute of Biology 65
7. Natural Environment Research Council 69
8. The Met Office 72
9. Economic and Social Research Council 84

LIST OF REPORTS

SCIENCE AND TECHNOLOGY COMMITTEE REPORTS IN THE CURRENT PARLIAMENT

Session 1997–98

First Report: The Implications of the Dearing Report for the Structure and Funding of University Research (HC 303)

Second Report: The Year 2000—Computer Compliance (HC 342)

Third Report: Glaxo Wellcome and SmithKline Beecham: The Merger Proposals (HC 627)

Fourth Report: The Cloning of Animals from Adult Cells (HC 1039)

Fifth Report: British Biotech (HC 888)

Sixth Report: Science and the Comprehensive Spending Review (HC 1040)

First Special Report: The Government's Response to the Committee's Fourth Report, Session 1996–97, The Research Council System: Issues for the Future (HC 302)

Second Special Report: The Government's Response to the Committee's Third Report, Session 1996–97, The Natural Environment Research Council and Research into Climate Change (HC 306)

Third Special Report: The Government's Response to the Committee's First Report, Session 1997–98, The Implications of the Dearing Report for the Structure and Funding of University Research (HC 799)

Fourth Special Report: The Government's Response to the Committee's Fifth Report, Session 1997–98, British Biotech (HC 1185)

Session 1998–99

First Report: The Scientific Advisory System: Genetically Modified Foods (HC 286)

Second Report: The National Endowment for Science, Technology and the Arts (HC 472)

Third Report: The Scientific Advisory System: Mobile Phones and Health (HC 489)

Fourth Report: The Regulation of the Biotechnology Industry (HC 535)

First Special Report: The Government's Response to the Committee's Sixth Report, Session 1997–98, Science and the Comprehensive Spending Review (HC 234)

Second Special Report: The Government's Response to the Committee's Second Report, The National Endowment for Science, Technology and the Arts (HC 822)

Session 1999–2000

First Report: The Year 2000—Computer Compliance: Follow-Up (HC 37)

Second Report: Engineering and Physical Sciences Based Innovation (HC 195-I)

Third Report: Scientific Advisory System: Diabetes and Driving Licences (HC 206-I)

Fourth Report: Glaxo Wellcome and SmithKline Beecham (HC 207-I)

Fifth Report: Government Expenditure on Research and Development: The Forward Look (HC 196-I)

Sixth Report: Cancer Research—A Fresh Look (HC 332-I)

Seventh Report: The Government's Expenditure on Research and Development: The Forward Look—The Government's Reply (HC 723)

First Special Report: Government Response to the Committee's Second Report, Engineering and Physical Sciences Based Innovation (HC 451)

Second Special Report: Joint Working with the Lords Science and Technology Committee (HC 980)

Third Special Report: Government Response to the Seventh Report of the Science and Technology Committee on the Government's Expenditure on Research and Development: The Forward Look—The Government's Reply (HC 981)

Session 2000-2001

First Report: EQUAL (Extend Quality Life) (HC 43)

Second Report: Corus plc—Research and Development (HC 110)

First Special Report: The Work of the Science and Technology Committee 1997–2000 (HC 44)

MINUTES OF EVIDENCE

TAKEN BEFORE THE SCIENCE AND TECHNOLOGY COMMITTEE

WEDNESDAY 15 MARCH 2000

Members present:

Dr Michael Clark, in the Chair

Mr Nigel Beard
Mrs Claire Curtis-Thomas
Dr Ian Gibson
Mr Robert Jackson
Dr Lynne Jones
Dr Ashok Kumar
Mr Ian Taylor
Dr Desmond Turner
Dr Alan W Williams

Memorandum submitted by Sir John Houghton CBE, Co-Chairman of Working Group I of the Intergovernmental Panel on Climate Change (IPCC)

1. The IPCC was set up in 1988 jointly by two United Nations bodies, the World Meteorological Organisation and the United Nations Environment Programme, its purpose being to provide authoritative assessments of anthropogenic climate change. Three Working Groups (WGs) were formed, WGI to assess the Science of Climate Change and WGs II and III to assess the impacts, adaptation, mitigation and policy options associated with Climate Change. I have served as WGI Chairman or Co-chairman (each WG now has two co-chairs one from a developed country and the other from a developing country) since 1988.

2. Annex I describes the IPCC and its workings in some detail. I am also sending for members of the Committee copies of the Summary for Policy Makers and the Technical Summary of the IPCC 1995 Report.[1] The essential points to note are that (1) through the involvement of a high proportion of the world's climate scientists (including many of the world's leading scientists in the area) ownership of IPCC reports by the world scientific community has been achieved, and (2) through the involvement of governments in the review process and in the approval of the Summary for Policymakers, ownership of the reports by the world's governments has also been achieved. The IPCC has therefore played a key role in advising governments on the science, the impacts and the policy options regarding climate change.

3. The UK Meteorological Office has been involved in research into Climate Change since the 1960s when there was concern that human alteration of the climate might be used as a military weapon. Because of its strong capability in atmospheric and ocean modelling it became one of the world's leading centres in climate modelling, a position which was further strengthened by the establishment of the Hadley Centre in 1990 with joint funding from the Department of the Environment and the Ministry of Defence. The Hadley Centre also houses the Technical Support Unit (TSU) for WGI of the IPCC, a small group that organises the international process for the preparation and review of the IPCC reports. The availability of the best scientific and technical advice especially from the Hadley Centre and the IPCC has enabled the UK government to play a crucial role in the international negotiations concerning climate change in the context of the Framework Convention on Climate Change (FCCC).

4. I now address the particular questions raised in your letter to me requesting evidence.

5. Question 1. What other reasonable potential alternative explanations for climate change, other than increasing levels of CO_2 exist? How does the IPCC assess these? How are its funds disseminated?

First it is important to recognise the substantial natural variability of climate that arises especially because of interactions between the various components of the climate system (the atmosphere, the oceans, the land, the ice and the biosphere). Superposed on these variations are climate changes due to changes in factors that influence the climate. These factors may be due to natural causes (eg changes in solar radiation or volcanic eruptions emitting large quantities of dust into the atmosphere) or to human activities (eg emissions of "greenhouse" gases such as CO_2, methane etc or of gases such as SO_2 that lead to the production of particles in the atmosphere). In any assessment of past or future climate change all of these need to be considered. A large proportion of the IPCC reports is concerned with careful assessment of the available evidence from observations and from appropriate analysis (including modelling) regarding these factors, both natural and anthropogenic. The IPCC's clear conclusion stated in all its reports is that the influence of the anthropogenic factors, especially emissions of CO_2 is likely to be by far the dominant factor determining climate change during this century.

Regarding the dissemination of IPCC funds, these are used for the support of a small international secretariat in Geneva, for the cost of IPCC meetings and for the cost of the participation of scientists from developing and EIT countries in IPCC meetings including those of the Working Groups. This latter is essential if the IPCC is to involve scientists from a wide range of countries in its work. In addition, the UK government provides funds to support the WGI TSU to which I referred above. The IPCC is a cost effective organisation and considering its work load it employs comparatively few staff.

---

[1] Not printed.

6. Question 2. Do you think the Government sufficiently scrutinises alternative explanations for climate change, other than increasing concentrations of CO_2 before developing policy? By what means is this achieved? What part does the IPCC play in this?

As I explained in (5) above the variety of factors influencing climate change is well understood by government, the main source of comprehensive information available being the IPCC assessments. These assessments distinguish clearly between what is known with reasonable certainty and the areas where there is a lot of uncertainty and debate amongst scientists. Since the hundreds of scientists involved with the IPCC come from a wide range of countries, backgrounds and scientific disciplines, a wide range of genuine scientific opinion is represented. One of the leading "sceptics", Professor Richard Lindzen, is a lead author for one of the chapters of the IPCC report currently in preparation. However, there are a few scientists, many of whom are supported by fossil fuel companies, who tend to employ the media rather than the scientific literature to express their view that the IPCC is overstating the role of greenhouse gases in climate change. There are a few others, many of whom are involved with "green" groups, who equally vocally complain that the IPCC fails to recognise adequately the more damaging anthropogenic effects on climate that might possibly be realised. Inevitably too there are others with very limited or no real scientific knowledge who use the media or who are used by the media to put forward contrary views. The government is therefore made aware of and exposed to (and sometimes replies to) the wide range of views that exist both scientific and political.

7. Question 3. Do you agree that climate change models provide the most robust means of gaining information on which to base policy decisions? What other means could or should be used?

The available scientific evidence comes from observations, analysis of observations and models. It is sometimes thought that these are alternative sources of evidence. That is not the case. Observations on their own are of limited use; they need to be interpreted. Models provide the main means for the interpretation of the wide range of observations that are relevant to climate change. Observations are therefore input to models; models are of limited value without observations.

Climate models are generated from the equations that express the physical and dynamical laws that determine the response of the atmosphere, the oceans and other parts of the climate system to the natural or anthropogenic factors controlling the climate that I mentioned in para (5) above. The simplest possible climate model is just one of these equations. Models as used in climate science, therefore, possess a sound scientific basis. Their importance arises from the fact that they are an essential tool for gaining understanding. Because all the influences on the climate lead to non-linear responses (ie there is no simple proportionality between forcing and response), without the use of models it is impossible to sum the responses of the climate to the various influencing factors. There are those who speak loudly about the inadequacies of models and try to use hand-waving arguments instead. It is true that, because of the complexities of the climate system, models are inadequate in various respects and have to be carefully appraised. However, hand-waving arguments can in no way replace even the simplest of models because they are completely unable to allow for the non-linear character of the factors involved.

8. Question 4. What actual appraisal of climate change models has been performed by Working Group I of the IPCC and with what conclusions?

The IPCC reports contain results from and assessments of a wide variety of models covering different aspects of the problem of climate change—for instance models of the carbon cycle, of aerosol production, of atmospheric processes an circulation, of ocean circulation etc. The most sophisticated models are those that couple together the atmospheric and oceanic circulations together with descriptions of the hydrological cycle and the behaviour of sea ice. The large number of studies comparing results from different models have provided an important input to the IPCC assessment process; a substantial proportion of IPCC reports has been taken up with the comparative appraisal of model results. The IPCC's conclusion regarding the use of models expressed in the Summary for Policymakers of the 1995 Report is as follows: "The increasing realism of simulations of current and past climate by coupled atmosphere-ocean climate models has increased our confidence in their use for projection for future climate change. Important uncertainties remain, but these have been taken into account in the full range of projections of global mean temperature and sea level change". Confidence in models has increased further since 1995 as model development has continued and as models have been tested more thoroughly and over a greater range of conditions.

1 March 2000

Annex I

A description of the formation and the work of the IPCC based on a draft prepared for an Environmental Encyclopaedia to be published by Wiley.

The Intergovernmental Panel on Climate Change: Working Group I.

John Houghton, Co-chairman, Working Group I (Scientific Assessment), Intergovernmental Panel on Climate Change (IPCC).

FORMATION OF THE IPCC

It has been known for well over 100 years that the presence in the atmosphere of gases such as carbon dioxide leads to a warming of the Earth's surface. In 1896, Sverre Arrhenius, a Swedish chemist, first computed the amount of warming that would occur should the amount of carbon dioxide in the atmosphere double. In the 1960s, observations made by Charles Keeling from the Manna Loa Observatory on Hawaii showed that atmospheric carbon dioxide concentrations were increasing significantly. However, it was not until the 1980s that it began to be generally recognised that increased human activities involving the burning of fossil fuels (coal, oil and gas) was resulting in a large increase in atmospheric carbon dioxide and a probable doubling of its pre-industrial concentration before the end of the 21st century. The possibility of serious consequences to the world's climate was increasingly raised by scientists and those with environmental concern.[2] This is an example of global pollution—pollution by one person locally that has global effects.

In 1988 an international conference was held in Toronto which for the first time pressed for specific international action to mitigate climate change. It was in that year too that world leaders began to speak out about it; for instance, Mrs Thatcher expressed her concern in a speech to the Royal Society of London that was widely publicised. It was therefore timely that in 1988 a new scientific body to address the issue, the Intergovernmental Panel on Climate Change (IPCC) was set up jointly by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). Bert Bolin from Sweden, a scientist with a distinguished record of contributions to the science of climate, agreed to chair the IPCC. Three Working Groups were established, WGI to address the science of anthropogenic climate change, WGII to address the impacts of climate change, and WGIII to address the policy options. IPCC WGI has prepared comprehensive assessments of the science of anthropogenic Climate Change in 1990 and 1995 together with a number of other more limited assessments and technical reports. A further comprehensive report is being prepared for publication in 2001.

In its structure the IPCC followed closely the structure of the Assessment Panels of the Montreal Protocol which had been set up in 1987 by UNEP and WMO to address the problems of the depletion of stratospheric ozone by CFCs and related chlorine containing chemicals—another example of global pollution. Through the negotiation of the Protocol, with its arrangements for inputs from scientists and other experts, methods had begun to be developed in the international community through which global pollution problems could be addressed. Although this problem addressed by the Montreal Protocol was a more limited one than that of global climate change, especially in the range and size of the human activities that contribute to it, it was appropriate that the IPCC should build on this experience in addressing climate change issues. The development within the IPCC of ways to involve large numbers of scientists and of formal procedures for peer review in turn influenced the ongoing work of the Assessment Panels of the Montreal Protocol.

THE IPCC WGI 1990 REPORT[3]

It was agreed at the first meeting of the IPCC that a new assessment of the whole issue of anthropogenic climate change should be prepared. There had, of course, been assessments before of the climate change issue, notably one published in 1986[4] organised under the auspices of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council for Science (ICSU) again under the chairmanship of Bert Bolin. The IPCC saw its task as updating previous assessments but with a difference. Previous assessments had involved relatively few of the world's leading climate scientists. Because of the global nature of the issue that brought with it a large measure of international concern, the IPCC's ambition from the start was to involve as many representatives as possible from the world scientific community in the new assessment.

---

[2] A comprehensive account of Global Warming and Climate Change can be found in, John Houghton, *"Global Warming: the Complete Briefing"* second edition, Cambridge University Press, 1997.

[3] Climate change, the IPCC Scientific Assessment, eds JT Houghton, GJ Jenkins and JJ Ephraums, Cambridge University Press, 1990.

[4] SCOPE 29, The Greenhouse Effect, Climatic Change and Ecosystems, eds Bert Bolin, Bo Doos, Jill Jager and Richard Warrick, John Willey 1986.

To assist in the preparation of the WGI report, a small Technical Support Unit was set up within the part of the UK Meteorological Office at Bracknell which was concerned with Climate Research. The report comprised 11 chapters totalling over 300 pages dealing with different components of the scientific issue together with a Policymakers' Summary and an Executive Summary. Twelve international workshops were held to address these different components. One hundred and seventy scientists from 25 countries contributed to the report either through participation in the workshops or through written contributions. A further 200 scientists were involved in the peer review of the draft report. The thorough peer review played an important part in ensuring the achievement of a high degree of consensus amongst the authors and reviewers regarding the report's conclusions.

The Policymaker's Summary (20 pages) together with its Executive Summary (two pages) were based on the conclusions presented in the chapters and were prepared particularly to present to those without a strong background in science a clear statement of the status of scientific knowledge at the time and the associated uncertainties. In preparing the first draft of the Policymakers' Summary, the Lead Authors of the chapters were first involved; it was then sent out for the same wide peer review as the main report. A revised draft of the Summary was then discussed line by line at a Plenary Meeting of the Working Group attended by government delegates from 35 countries together with lead authors from the chapters. The final wording was agreed at that meeting. A flavour of the style and content of the report is given by the first few paragraphs of the Executive Summary that read as follows:

We are certain of the following:

- there is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be;
- emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.

We calculate with confidence that:

- some gases are potentially more effective than others at changing climate, and their relative effectiveness can be estimated. Carbon dioxide has been responsible for over half the enhanced greenhouse effect in the past, and is likely to remain so in the future;
- atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. The longer emissions continue to increase at present day rates, the greater reductions would have to be for concentrations to stabilise at a given level;
- the long-lived gases would require immediate reductions in emissions from human activities of over 60 per cent to stabilise their concentrations at today's levels; methane would require a 15 to 20 per cent reduction.

Based on current model results, we predict:

- under the IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C per decade); this is greater than that seen over the past 10,000 years. This will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 and 3°C before the end of the next century. The rise will not be steady because of the influence of other factors.

Later sections of the summary addressed the scientific uncertainties and the question of the degree to which anthropogenic climate change had been observed in the climate record.

Over the period of the preparation of the IPCC report, a significant change occurred in the attitudes of the scientists involved. To begin with, many scientists felt that the scientific uncertainty was too large for any useful statement to be made regarding future climate change. However, increasingly the scientists realised their responsibility to articulate carefully and honestly the available knowledge. This responsibility seemed all the more important because many individuals not possessing much expert scientific knowledge were making forecasts of future climate change—often of an extreme kind. Also, it was increasingly recognised that there was enough certainty in the science to provide meaningful information regarding the likely future provided that the uncertainty was also fully explained.

Consensus amongst Scientists and by Governments

Many of the world's leading scientists in the field of climate and climate change contributed to the report. Inevitably they came mostly from developed countries. However, a significant number of contributors from developing countries were also involved. That so many of the world's scientists contributed or were involved in the review process meant that there was a genuine feeling of ownership of the report by the world scientific community.

The IPCC process led to a significant degree of consensus. It is sometimes pointed out that "consensus" amongst scientists is not necessarily a sign of scientific health; argument and disagreement are seen to be more usual building blocks of scientific advance. But the "consensus" achieved by the IPCC is not complete agreement about everything. It is agreement particularly about what we know and what we do not know—distinguishing clearly those matters about which there is reasonable certainty from those where there remains much uncertainty and where there continues to be lively debate and disagreement. It is this limited "consensus" which is reflected in the Executive Summary of the 1990 IPCC Report which has been widely acclaimed for the clarity and crispness of its presentation.

It was clear from an early stage that not only was the scientific content of the assessment important but also the way in which it was presented. Scientists left to themselves do not always recognise what is relevant to policymakers or present their material with the maximum clarity. Further, the presentation of a scientific document can appear to a policymaker to convey a political message even though none was intended.

It has therefore been helpful in the presentation of the science of climate change to involve policymakers themselves or their representatives in the formulation of the summary of the reports. For instance they were full participants in the government review process and in the Working Group Plenary Meeting which agreed the wording of the report. The report was greatly improved in its relevance and clarity through their participation. In addition because governments participated in the process, they felt to own the report.

The IPCC was therefore able to provide to the Earth Summit at Rio in 1992 a clear assessment of the science of climate change that was owned both by the world scientific community and by governments. These characteristics were essential to providing governments with the confidence to formulate and sign the Framework Convention on Climate Change at that 1992 Conference and to take appropriate action. They have continued to be essential in the generation of subsequent reports which have provided input to the on-going work of the FCC, for instance to the Kyoto Protocol of 1997.

The 1992, 1994 and 1995 IPCC Reports

As soon as the 1990 report was complete, the IPCC began work on further reports. In 1992, in time for the Earth Summit, WGI produced a report updating what was known about greenhouse gases[5], their sources and sinks, and about observations and modelling of climate change. In addition the 1992 report developed various emission scenarios for the emissions of greenhouse gases over the 21st Century based on a variety of assumptions regarding factors such as world population, economic growth, availability of fossil fuels etc.

The 1994 report updated the information and analysis regarding the radiative forcing of the various greenhouse gases[6]. Of particular importance was the new work carried out on the profiles of emissions of carbon dioxide and other greenhouse gases which would lead to the stabilisation of these gases in the atmosphere at different levels of concentration.

By 1995, when the IPCC produced its second comprehensive assessment[7], five years after the first assessment in 1990, the community of scientists involved with the IPCC had become substantially greater. More scientists from more countries were involved both in the report's preparation (about 480 scientists from more than 25 countries) and in its review (over 500 from 40 countries). The participants at the Plenary Meeting of Working Group I that approved the Summary for Policymakers included 177 delegates from 96 countries, representatives from 14 non-governmental organisations and 28 Lead Authors. Regarding climate change over the next century and its likely impacts the messages of the 1995 report were essentially the same as those of the 1990 report. Some further detail had emerged during the five years in between, especially regarding the likely contribution to climate change from atmospheric aerosols—the fine particles that are present in the atmosphere as a result of industrial activity. Also, there was more confidence amongst scientists that the historical increase in global average temperatures that has occurred since wide-scale industrialization might be the result of anthropogenic change. The WGI Plenary Meeting debated for a considerable time how to express this somewhat greater scientific confidence in the interpretation of the recent climate record—although still surrounded by much uncertainty. A sentence carefully crafted by the meeting was unanimously agreed by the delegates: "the balance of evidence suggests a discernible human influence on global climate."

---

[5] Climate Change 1992: the Supplementary Report to the IPCC Assessment, eds J T Houghton, B A Callander and S K Varney, CUP, 1992.

[6] Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Scenarios, eds J T Houghton, L G Meira Filho, J Bruce, Hoesung Lee, B A Callander, E Haites, N Harris and K Maskell, CUP, 1996.

[7] Climate Change 1995: the Science of Climate Change, eds J T Houghton, L G Meira Filho, N Harris, A Kattenberg and K Maskell, CUP, 1996; Climate Change 1995: Impacts, Adaptation and Mitigation of Climate Change, eds R T Watson, M C Zinowera and R H Moss, CUP, 1996; Climate Change 1995: Economic and Social Dimensions of Climate Change, eds J Bruce, Hoesung Lee and E Haites, CUP, 1996.

THE FCCC AND THE IPCC

The United Nations Framework Convention on Climate Change (FCCC) signed by close to 160 countries at the Earth Summit in Rio de Janeiro in June 1992 sets the context in which international discussion regarding appropriate action can be pursued. The development of the Convention's agenda clearly requires continuous scientific and technical input. The Conference of the Parties (COP) to the FCCC has set up a Subsidiary Body for Science and Technological Advice (SUBSTA) to organise this input. The IPCC is working closely with SUBSTA through a Joint Working Group (JWG) to ensure that IPCC assessments are geared to provide the detailed scientific and technical input required.

The objective of the FCCC is contained in Article 2. It recognises the need to prevent continued change of the climate. It reads as follows:

> "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

The IPCC has been at pains to explain that what constitutes "dangerous" is a policy not a scientific decision. But the need to make such policy decisions immediately raises many scientific and technical questions. For instance, what carbon dioxide emission profiles will lead to stabilisation of atmospheric concentration and by when? What effect will current proposed emission limitations by developed countries have on atmospheric concentrations? What technologies, policies and measures might be available for mitigating climate change? How vulnerable are different regions of the world to possible climate change? To assist in answering these questions the IPCC has produced a series of Technical Papers addressing the detail of some of the issues involved.

An issue which has been highlighted by the third session of the COP at Kyoto in 1997 is that of the contributions which are made by deforestation, aforestation, reforestation and changes in land use to the sources or sinks of greenhouse gases, especially of carbon dioxide. This is an area where what is meant by different human activities (eg de-, a-, or re-forestation) requires very careful definition, where there is much scientific uncertainty and where there are large possibilities for the propagation of perverse incentives. The IPCC is already very involved in this area through its work on the development of detailed guidelines[8] for the production of national inventories of greenhouse gases which include both sources and sinks. It is the IPCC Guidelines to which the Kyoto Protocol refers. A Special Report on Land Use and Forestry addresses these issues[9].

THE FUTURE WORK OF THE IPCC

Preparation is now starting for a third comprehensive assessment report to be completed in 2001 that will take into account the large growth in research in both the natural sciences and the social sciences in topics related to climate change, its impacts and its mitigation. In carrying out this assessment the IPCC will ensure that it is relevant to the policy needs of the FCCC and will also ensure that the process of assessment continues to be open, transparent and rigorous and continues to involve as many in the world scientific community as possible.

The question is often asked as to whether the IPCC provides a pattern or a model for providing the means for scientists from all disciplines to provide input to policy determination in other areas of concern. The elements which we have mentioned which have been critical to the success of the IPCC have been those of: (1) ensuring the widest possible participation by experts from all relevant disciplines; (2) ensuring a clear separation between scientific assessment and policy determination and (3) through the close involvement of the expert community, of governments and, more recently, of relevant industry, ensuring wide ownership not only by the community of experts but also by those who have a stake in the policy process. Although anthropogenic climate change is perhaps the largest and most complex problem concerned with the global environment that we face, it is not unique. Models similar to that of the IPCC with its essential elements could be applied elsewhere. The development of the work of the IPCC has demonstrated the enormous capacity for the international community to work together towards the common aims of care for humanity and care for the environment and provides encouragement in the belief that problems as complex as that of climate change are capable of solution.

---

[8] IPCC Guidelines for National Greenhouse Gas Inventories. IPCC Secretariat, World Meteorological Organisation, Geneva, 1995.

[9] IPCC Special Report on Land Use Change and Forestry due for completion in May 2000—reference to completed in proof.

Examination of Witness

Sir John Houghton CBE, Co-Chair Working Group I, Intergovernmental Panel on Climate Change, was examined.

Chairman

1. Sir John, welcome to the Science and Technology Committee, and not for the first time. You appeared before this Committee in the last Parliament, although I have only been its Chairman since the last election. You last came to this Committee in 1996 to give evidence on climate change, but I also remember you appearing before the old Energy Committee which I chaired, and you may recall that. So we have worked out that the world is cycical and so are your appearances before Select Committees. We are not looking into global warming, as such, we are doing a major report into scientific advice to Government, which seeks clarification of the ways in which scientific advice is used and the purposes of that use, so we are taking as granted there is climate change. This is to be the fourth of our four chapters of this report, and we have been publishing them as we complete each one. The first looked at scientific advice relating to genetically-modified foods, the second at that relating to mobile 'phones. The third was on diabetes and driving. And this will be the last. Sir John, would you please say a few words about yourself and your involvement in climate change, as briefly as you think is appropriate?

(*Sir John Houghton*) Most of my time at the moment is taken up with the Intergovernmental Panel on Climate Change, with the Scientific Assessment Working Group of that panel. I was Chief Executive of the Meteorological Office from 1983 to 1988.

2. Thank you very much indeed. Could you just give us a brief overview of the IPCC and Working Group I which you Co-Chair?

(*Sir John Houghton*) Yes. We were founded in 1988 jointly by the World Meteorological Organisation and the United Nations Environment Programme. Our main task is to produce comprehensive assessments of human-induced climate change to try to make them as authoritative as we can, to involve the world scientific communities, so far as we are able to do that, and to produce documents that are therefore very useful to scientists and politicians and industrialists and, in fact, the general public around the world. We have produced reports in 1990, the very first one was in 1990, the second comprehensive report was in 1995, though in the meantime, between 1991 and 1995, as Working Group I, we produced two interim reports, in 1992 and 1994, on specific topics. And then we are preparing a new one now, a new comprehensive report for next year, 2001, which is more complicated, and it will be longer, I am afraid, it involves more people, it involves more disciplines, but it will be of the same kind as we produced before. The other report we produced recently, as Working Group I, jointly with Working Group III, was the report on Climate Change and Aviation, and the new thing about that was we involved the aviation industry, it was done at the request of ICAO, the International Civil Air Transport Organisation, they were involved in setting it up, they helped us to involve the aircraft industry, that is the manufacturers of aircraft as well as the operators. And that was a very interesting experience for us, because it was very good to work with industry in that way, and it was very good for them to work with us, because they learned a great deal in that process.

3. When you went through, a moment ago, the lists of people that the report could interest and who it could help, you actually did not mention government, you talked about the scientists, industrialists, students; would you think those reports could be valuable to government too?

(*Sir John Houghton*) Sorry; that was a real omission, if I missed it out.

4. Okay, fine; so long as it was.

(*Sir John Houghton*) The main purpose of the IPCC is to inform governments, of course, because we are an intergovernmental body, so governments are automatically informed by what we do, because they actually control what we do and take a substantial part in what we do. And, further, we are recognised as a key body to inform the process of the Framework Convention on Climate Change, which, of course, was signed at the Earth Summit in Rio in 1992; and there have been various meetings of the Conference of Parties, we have just gone through COP5, I think, COP6 is due next year, and the most significant of those was the one at Kyoto, which formulated the Kyoto Protocol.

5. Now, as I understand it, and I think as this Committee understands it, the IPCC's second assessment report has been very influential in developing policy on climate change, not just here in the United Kingdom but throughout the world. I wonder if, just in a few moments, you could tell us the processes by which these assessments were reached?

(*Sir John Houghton*) Yes. It has gradually evolved, over the period of the IPCC, since 1988, the object being, as I say, as I have explained, I think, to involve as many scientists as we can; and therefore we get lists of climate scientists around the world, and as many countries as we can. We invite them to contribute material for our report, that is one of the first things we do, we invite them to be contributors, we invite nominations for lead authors to the chapters of the report, from around the world, we then have a procedure for selecting lead authors and selecting contributors. Typically, for any given chapter, we will have between ten and 20 lead authors across the disciplines and with a suitable geographical mix, or, at least, the best geographical mix we can achieve,

[**Chairman** *Cont*]
given the requirements of actually doing the work, of course, at the same time. The chapters then get written in draft, they then get circulated, informally first, to some key scientists for them to comment; those comments are taken into account. They then get circulated again to the whole scientific community, to anybody who wants to receive it, worldwide, and review it; that is a completely open invitation to the world scientific community to carry out reviews of it.

6. It is a form of peer review, is it not?

(*Sir John Houghton*) It is a peer review; it is the biggest peer review, I think, which occurs in science, that I know of, certainly, at the present time.

Mr Beard

7. How much difference of opinion is there between the people who contribute to this exercise; is it a fairly narrowly columnated set of views, or is there a wide diversity of them?

(*Sir John Houghton*) We are taking people, of course, from very different places, from different disciplines, from around the world, they have a wide variety of views. They tend to break down, of course, into things that people are fairly sure about, as a whole, so you have a consensus of views about the main aspects of climate change, and then there is a wide diversity of views about those matters where we are pretty uncertain; and those views come out in the documents.

8. What are, say, the two biggest areas where the greatest uncertainty would arise and who would be the larger numbers of people with different views from the central opinion?

(*Sir John Houghton*) If you take the feedback effect of clouds, for instance, the impact of clouds, there is a lot of scientific uncertainty, if the climate warms up; and there is no real uncertainty in the fact of global warming, the fact of climate change, the fact of the greenhouse effect, those are well-established, scientific matters. But where there is uncertainty is just how big the feedbacks are, what effect they will have not only on a global scale but on a regional scale. And one of the most uncertain of the feedbacks, and that is why I mention it, is the effect of clouds, because if you increase the average temperature you increase the amount of water vapour, you change the cloudiness in some regard, and just how those changes will affect the climate change itself. And there are observations of how clouds behave, and there are, of course, models which are generated to try to explain how they behave and describe how they behave, to try to fit with the observational scene. And if you were talking in terms of global average temperature increase that may occur because of global warming, then you get a factor of about three between the most negative feedback expected from clouds by some people, and the most positive feedback expected from clouds by others. In fact, the situation is probably more complex than that, because clouds probably behave differently in different places at different times.

Chairman

9. My final question, before we go to Mr Taylor, and this is about the summaries that the IPCC makes for policy-makers. Can you please let us know how these summaries are arrived at, how they are disseminated to various governments, and how much scientific and technical information is included in them: how they are arrived at, how they are disseminated, and how scientific are they?

(*Sir John Houghton*) How they are arrived at; it is the end of the process. The scientific chapters are written by the scientific community, and reviewed, of course, by that community. And, finally, a subset of those scientists will write a draft of a policy-maker's summary; that policy summary then goes out to review, to the scientific community and to government, those review comments come back, and a revised text, or a draft revised text, is produced, with options in it, brackets, and so on, which is then presented to an intergovernmental meeting. That intergovernmental meeting, typically, will have of the order of 100 countries present, it will have government delegates, it will have the main lead authors, the convening lead authors, representative lead authors, for all the chapters, representing the scientific community, and we go through that document, word by word, sentence by sentence, and try to reach agreement, in that big meeting, on the text. Now that is quite a big task, especially as it is conducted, of course, in simultaneous translation, in six languages, but the procedure, as we have developed it, is such that, of course, it is a scientific discussion, it is not a political negotiation, so the science is either right or it is wrong, or it has to be expressed in certain different ways in order to make it acceptable to the scientific community, or, indeed, to be understandable by the politicians present; and we go through that procedure. And so far we have actually succeeded in reaching consensus on all those policy-maker summaries that we have generated; they are changed a great deal in the process of that meeting, they are improved in the process of that meeting, each of them has been substantially improved both presentationally and scientifically by that process. Because the government delegates demand that they are clear, they object to things that appear to be inconsistent, they want sentences that are relevant and that are understandable by them, and the process of generating that actually creates a better and more accurate and more acceptable document both to the scientists and the politicians, as a result of that process.

Dr Jones

10. Can I just remind you that, when you gave evidence to our predecessor Committee, you said that there was a weakness in the process of looking at the total international programme, because there is no UK body which sits over the climate agenda as the body responsible for making sure that the UK contributes in a sensible way. Have things improved since then, who is doing that now, and is enough priority being given in departmental budgets—the Ministry of Defence and DETR—to research into climate change?

[Dr Jones *Cont*]

(*Sir John Houghton*) That is, of course, a different issue from the IPCC, the IPCC is an assessment body, the IPCC does not direct research, it makes some suggestions about the research which is necessary but it is not in any way in charge of international or national research programmes. That weakness, which was apparent in 1996, perhaps, when I gave evidence before, is still there, there is still a problem in putting the whole of climate science together, not just in the UK but in other countries too. And that weakness arises because it is a multi-disciplinary science which is involved; there is the science of meteorology, oceanography, a lot of biological components now, ecology, and so on, are all involved in the whole of climate science, not to mention, of course, also, the social sciences, which also come into the whole of the picture when you are looking at climate science problems. And putting all those things together into a coherent and sensible national research programme is still a difficulty, because different subjects are addressed in different ways, by different Research Councils. And, although the Research Councils are getting together in a variety of ways and it is improving, it is improving very substantially, I think, from what it was in 1996, there is still difficulty in putting the total programme together, and not only nationally but also internationally, because of this difficulty that there is no one world body that picks it all up.

Mr Taylor

11. Can I take you back to your earlier comments about differences between scientists on the whole problem of climate change? You implied it was a difference of emphasis, but there are some people who actually do not go along with the consensus at all, that it is caused by greenhouse gases and carbon dioxide. How much, as an assessment body, do you take those views into account?

(*Sir John Houghton*) We distinguish between those who put out views who do not know enough science to put out sensible views, if I might put it that way, and there are some of those who use the media to put over material which has no scientific basis and which would be discarded by all respectable scientists who are working in the field. There are others who disagree with our conclusions, substantially, in some cases. One of those, in fact the most distinguished of those, Professor Richard Lindzen, is one of our lead authors in our current assessment report; he agreed to join us for that purpose, and he puts over his particular scientific view, articulately, and there is a lot of debate on that particular chapter because of his presence. And that, we feel, is very good, because we want to take into account all the genuine scientific views which are around, which are important to the whole debate.

12. But you accept, therefore, that there is an element of uncertainty about the whole issue?

(*Sir John Houghton*) It is not a certain science, by any means, it is quite an uncertain science, in some regards, but we are much more certain about some things than we are about others.

13. But would you accept that there might be different political reactions, or actions, that would stem from different views? If you take one particular view, that climate change is entirely the cause of CO2, then the action that government might take would be different from an alternative conclusion, that CO2 plays very little part. You mentioned cloud cover earlier. There is a whole series of possibilities which might cause differences in the actions that governments need to take?

(*Sir John Houghton*) That is true, of course, and the action that governments take will depend on other factors as well, economic factors, and whether they feel they are going to be losers or gainers when climate change is actually occurring, or occurring on a larger scale. But surely there are lots of people also who are motivated, of course, by their own vested interests, and there are very strong lobbies, from the energy industry in the United States, or a very strong oil and coal lobby, which has been very active, it has been selecting material in an irresponsible way, in order to try to persuade the US Congress and other bodies in the US that there is no need to take action of any kind. Now they are distorting the story very substantially, and the scientists in the IPCC have been disturbed by that sort of process going on, supposedly in the name of science, but which is distorting a balanced view of the science. You see, there is a lot of information, a lot of data, a lot of observations, a lot of modelling results, and if you are going to produce a balanced assessment of what climate change will be, we can say there is uncertainty, we can say the problem lies between certain limits, and we explain that. Now, those who want to put over a particular political view, or a particular vested interest view, will tend to concentrate on the bottom end, or even below the bottom end, of what might occur. There are those, of course, on the other hand, people who work for green organisations, quite often, who will try to say we have not emphasised the uncertainty anything like enough, and it may well be that there could be almost calamitous events; they talk of Armageddons, and things of this kind, in order to try to put over a much more damaging view of what might occur. What we try to do, in the IPCC, is to put over a balanced view, given the nature of the science, given the uncertainties which are involved, and given our total understanding of it.

Mr Beard

14. To what extent do the dissenters dissent from the idea that the whole impact of climate change is caused by the greenhouse effect; and to what extent are there dissenters who believe that something like sunspots may be a contributory cause?

(*Sir John Houghton*) I am sorry? Could you please repeat the question?

15. To what extent are the dissenters all agreed that the greenhouse effect is the cause; and to what extent are there dissenters who believe that there may be some other factor contributing, like sunspots?

(*Sir John Houghton*) There are climate changes for a whole variety of reasons, of course, there are factors which cause climate change other than the increase of greenhouse gases. Climate change can

[**Mr Beard** *Cont*]

occur because the sun is changing, it can occur because of volcanic eruptions, it can occur just for natural variability reasons, because of interactions between different components of the system, between the atmosphere and the ocean, for instance, which causes natural variability and causes the changes in extremes, and we have got examples of all those in climate history; and, if you are going to assess climate change as it occurs now, we have got to take all those factors into account and say which is the most important contributor. The scientific community accepts, the whole scientific community, I think everybody who has any real scientific knowledge of the subject, accepts that greenhouse gases, in particular carbon dioxide, are a major cause of climate change. There are those who say it can all be explained by variations in the sun; that is not scientifically credible.

16. My question, really, is how much are those people represented in the range of dissidents that you were speaking of when you spoke to Mr Taylor?

(*Sir John Houghton*) The number of scientists who are working in the climate change field who would argue that it is all explained by the sun are very few indeed; in fact, there is probably no credible scientist in the world who would say that.

17. But partly?

(*Sir John Houghton*) But there are some who pick up information second-hand and who purvey it and sell it and talk about it as if—

Dr Gibson

18. Do they publish on it, in reputable journals?

(*Sir John Houghton*) No.

Dr Turner

19. Sir John, it sounds very much as if much of the controversy exists amongst those who are not dedicated primarily to the field; and, indeed, your memorandum notes that "the IPCC process led to a significant degree of consensus." That is, presumably, amongst professional scientists devoted to work on climate change. And you go further, to point out that sometimes consensus is not a sign of scientific health, argument and disagreement being useful promoters of scientific advance. So should we be concerned about the degree of consensus that exists amongst those who are dedicated to the study of climate change, or should we take caution in interpreting what they say, simply because there is so much consensus amongst them?

(*Sir John Houghton*) The degree of consensus among them is not perhaps as large as you imagine, but they have consensus only on some of the basic facts of climate change. The number of scientists we are talking about are many hundreds worldwide, we are talking of all the leading scientists in the field, in a wide variety of disciplines, they are not all working just in climate, they are working in things, topics, related to climate, and so on. So we are talking of a very large body of worldwide scientists who agree about the basic scientific issues which are at stake; they do not agree about all the detail, there is a lot of uncertainty in the detail, and that is well explained in the documents that we produce, and there is a range of possible climate changes that may occur, and we also try to explain that. As far as regional change is concerned, there is a great deal of uncertainty on what we can expect in the future, in any given place; nevertheless, the fact of climate change, I think, is very clear. The number of genuine scientists who would be considered as contributors to any scientific literature who are outside the range of uncertainty that we give, and who say there is no climate change occurring, of one kind or another, worldwide, is probably less than ten, in fact, probably less than five, actually. So we are talking of very small numbers, but some of those are very strongly used by the media, over all kinds, because the media are very interested in people who are right on the edges of what might be considered to be the general view. That does not mean the general view is wrong, I think you have to take into account the weight of evidence of hundreds of scientists worldwide who have spent many hours, many days, many months, actually, debating it, arguing about it, as we do. And that, I think, gives great strength to the sort of IPCC process that we have, in bringing together people of this kind and getting them to debate it, and actually changing their view in that process.

20. That is very helpful, Sir John. Can you help us further by just elucidating which you think are the important areas on which there is genuine debate and variation within the broader consensus, because those are areas which might well affect government policy?

(*Sir John Houghton*) I mentioned one, that is the role of clouds, which is probably our biggest single uncertainty in the whole business. There is the role of particles in the atmosphere, which are also anthropogenic, many of them, they come from burning forests, they come from sulphates emissions from power stations, creating sulphate particles, and so on; there is a lot of uncertainty about our knowledge of those. There is quite a lot of uncertainty here about the influence of the ocean and possible changes in the ocean which may occur. Rather less uncertainty about—it depends on the timescale you are talking about, on a hundred-year timescale there is rather less uncertainty about—the ice-sheets, on a longer timescale there is much more uncertainty about the ice-sheets. So there are many areas of uncertainty which we argue about and which we try to present.

21. Do you think there is any serious risk, then, that such a level of consensus that the IPCC has arrived at could lead to complacency on the part of governments around the world, so that they do not react, as possibly they need to, to guard against possible alternative explanations of climate change; do you do anything to guard against that happening?

(*Sir John Houghton*) We do try, in the IPCC, to look very hard at alternative explanations, and spend, actually, probably more time than we should on some of them, because they get so much publicity. We actually spend more time, for instance, on the solar variations, about which we have very little real scientific evidence but which some people have exploited in the media a great deal, and we spend more time on that than probably we should, considering how important it is scientifically. In fact,

[Dr Turner *Cont*]

we give more time to those things than we do to some of the more important elements of the science I have talked about.

Mr Jackson

22. Just on this very interesting question—in a sense, this is typical of a historical process in the development of all branches of science, that you have a period when you have a new subject, a new topic, and new techniques being brought to bear, when there is debate, and so forth, and then, hopefully, you move on to what becomes a consensus, which becomes established science and then you can take the thing forward. How far off, do you think, is the prospect of a sort of scientific consensus which establishes basic knowledge in this area; or actually are we going to have to look to a situation where the world is going to take political decisions in conditions of continuing, as it were, uncertainty and debate amongst scientists?

(*Sir John Houghton*) There always will be uncertainty in an area as complex as climate change, partially because our scientific knowledge is inadequate and partially because the nature of the climate system is not entirely predictable, there is a certain chaotic element, as it is called, chaotic being a technical term for something that is not perfectly predictable, in the climate system, as such, and that will always be there. So the amount of certain information that we can give will always be limited, and that would always be the case. But climate change is not unique amongst science; many scientific fields, including some of those you have already looked at, very much have the same flavour. I think what is almost unique, perhaps, about the way in which the climate change community has got together is that we have actually carried out a serious, wide-ranging, completely wide-ranging, debate in the scientific community, and attempted to put that science forward in a coherent, understandable, accurate and balanced form. And a great deal of effort has gone into that, the review process, I have talked about, in the IPCC; it actually takes months of the scientists' time, going through the review comments, which are many times greater in volume, very often, than the document on which they are commenting, so a great deal of effort goes into looking at all those comments. And this is the way in which the contrary views, of course, are properly taken into account and properly considered.

Dr Turner

23. Obviously, there are political differences between the member countries that make up the IPCC, in particular the States. What do you do, as IPCC, to try to resolve those differences?

(*Sir John Houghton*) The IPCC tries to ignore those political differences and tries to make sure that, in IPCC meetings, those political differences do not influence the debate. Now that, of course, is quite difficult, because, not so much with the USA but with the oil countries, in particular Saudi Arabia and some of the oil-producing countries, who are strongly fed with information by the American lobby, actually, the American coal and oil lobbyists, they can be very difficult, in some of these meetings, because they try very hard to weaken, or to change, or to alter, scientific conclusions. But, so far, we have been able to, I think, successfully resist those influences, because we stick very firmly to a presentation of the science, not the political interpretation of that science.

24. So I guess you would say that the main political differences, rather than being rooted in science and based on scientific evidence, are the other way round, that there is a very real danger of scientific evidence, in your context, being distorted by political and commercial influence?

(*Sir John Houghton*) Yes, that is true, and after each of our meetings we have had, when we have agreed policy-maker summaries, but to agree them, by consensus, with 100 countries, including those oil countries, is, I think, quite remarkable, and that, actually, under a discipline of science, when you say: "We are presenting the science, we are not presenting politics," it is possible to do that. There have always been some debates after those meetings, unhappiness, perhaps, on the part of some of the scientists, that we have bent too much in their direction because we have had big, big debates about it. I do not think we have bent very much at all, actually; but, nevertheless, it has appeared to some scientists that we have appeared to do so, that we have done so.

Dr Williams

25. Can I come in on this? That must be very frustrating for you, to have the US and the oil lobby, and so on. Do you take it as part of your responsibility, not only to collate the evidence and prepare these reports, but actually to go to the United States, to their conferences, and perhaps even lobby their politicians, congressmen, and so on, to do a kind of missionary job of educating the US public, their politicians and opinion-formers, that really they are out of line, they are out of step?

(*Sir John Houghton*) Yes; many of us do try to take opportunities in the United States to do that sort of thing. The IPCC, of course, as an organisation, is not a lobbying organisation, we do not take part in any political activity, we do not make policy statements, as the IPCC; though many of us, of course, involved in the IPCC, do go and try to explain the science, in the best way we can, as people, as scientists.

26. Is there a part of your budget to do with public understanding of science?

(*Sir John Houghton*) Yes; sure.

27. And where that public understanding is least, for political and energy and self-interest reasons, that is where the budget needs to be greatest, to try to persuade the politicians there that they need to come on board?

(*Sir John Houghton*) Our remit, of course, is really to do with assessment, is to publish an assessment and make that widely available, and, by doing that, we believe we are doing the sort of job you are describing. As an organisation, we do not have funds for campaigning, of any kind, though some of us, of course, do give lectures, and if we had an opportunity

[**Dr Williams** *Cont*]
to go and talk to a group of US congressmen we would take that, in order to try to explain the science in a way that is understandable to them.

Dr Kumar

28. Have you been able to persuade any congressmen, senators, given your presentations to them, have they actually changed their minds?

(*Sir John Houghton*) I have no evidence that any have changed their minds. I think I have strengthened the minds of some of those who were ready to listen, I do not think I have succeeded in changing the minds of those who were not prepared to listen.

Dr Turner

29. We have all met one who spectacularly refused to listen. I am sure you know who I mean. It has been argued that, the political differences that occur, that we have just referred to, make it more likely that scientific opinions that challenge the mainstream consensus have a value during the deliberations of the IPCC. Would you agree with that?

(*Sir John Houghton*) Yes. Although bodies like the Global Climate Coalition are an awful pain to us, in the way they lobby round, and so on, and sometimes it is almost unacceptable. Our meetings are open to observers from all non-governmental organisations, including the industrial lobby groups, and they are very active, of course, in our meetings, particularly the plenary meetings, when we are trying to agree policy-maker summaries; and although their activity is sometimes, we think, quite deplorable, but we still have them there because it is better to have them there than not to have them there. And, if I were asked, have they been a good thing, in helping us produce better reports, I would say, yes, we have produced better reports as a result of that.

30. They make you test your arguments that much more thoroughly?

(*Sir John Houghton*) Because they make sure we are absolutely honest and absolutely straight down the line, yes.

Mr Jackson

31. Just a question, or an informal observation, on this point about your lobbying role. Really, your motto is the motto of my old university—great is the truth and it will prevail?

(*Sir John Houghton*) Yes.

Dr Gibson

32. There are strong connections between the IPCC and the Hadley Centre, and they are both major contributors to government advice. Do you not think that is a kind of weakness, in a way, and perhaps the Government should extend its network out and get more independent advice from separate university researchers, or others?

(*Sir John Houghton*) The Government does, actually. The link between the IPCC and the Hadley Centre, I suppose, is quite strong, because the IPCC unit is housed in the same building; but the work of that IPCC unit is not primarily scientific, the work of the IPCC unit is organisational, it is getting the scientists worldwide involved in this process.

33. But your advice to government often looks very much the same, the language is different but the advice is similar, is it not? You have not had a real argument with them about anything yet, have you?

(*Sir John Houghton*) There are arguments with the Hadley Centre about various—

34. But in public?

(*Sir John Houghton*) Not public arguments, no. I think a lot of members of the Hadley Centre do play a part in the IPCC assessment, because they are one of the leading places in the world where you find scientists of this kind; it probably involves a wide range of university people, too.

35. Does the Government go independently to these other organisations besides you and the Hadley Centre?

(*Sir John Houghton*) Yes, it does, actually. For instance, the University of East Anglia is well represented in government advice.

36. Do they ever have contradictory advice to government, that you know of?

(*Sir John Houghton*) Their emphasis sometimes is quite different, and we have argued about certain things. I will not go into those details now, but there have been arguments between us, as you can imagine.

37. So you do not think there is a cosiness that makes you vulnerable to outside attack from green groups, as, for example, English Nature felt with the GMO debate?

(*Sir John Houghton*) That danger is always there, of course, if there are people who are working too closely together, and that danger must be watched; and government must go to a wide range of people to get its advice, to make sure that that cosiness is not a problem, I would agree with that.

Mr Beard

38. Sir John, your memorandum states that "the variety of factors influencing climate change is well understood by government". What evidence do you have that the reports and assessments produced by the IPCC have been understood and have been absorbed by the key policy-makers that you are addressing?

(*Sir John Houghton*) I think, if you take meetings, for instance, of the Framework Convention on Climate Change, those international meetings of politicians which are addressing the climate change issue, they are making a lot of use of IPCC material, in fact, they use it a great deal, and I think it has educated them very much in the science of climate change, and, indeed, in the possible impacts and the policy responses from the other IPCC working groups. So it has been a very influential body, in that respect.

39. Is not there a risk that people are uncomfortable with the uncertainties that you have been speaking of, and the brackets and tolerances,

[Mr Beard *Cont*]

and come down on a particular number and a particular interpretation without taking into account some of what are probably your reservations?

(*Sir John Houghton*) Our assessments do not give you one given number, they give you a range of numbers, in all cases, actually; they do not come down on particular answers to the problem, they give you a range of answers to the problem.

40. And are you satisfied that that sort of uncertainty is taken into account, when it comes to policy-making?

(*Sir John Houghton*) Very much so, yes. I say very much so; sometimes fairly simplistic single numbers are bandied about, and perhaps simplistic views of what may occur with climate changes are bandied about, and that is probably inevitable, given the fact that people like one given number, or to use a given piece of evidence. But if you take the range of material that comes out of bodies of that kind you will find all the uncertainties represented within those bodies.

41. The IPCC has concluded that the influence of human actions, especially emissions of carbon dioxide, is likely to be by far the most dominant factor determining climate change during this century. To what extent is the IPCC still involved in assessments of other factors and exploring other possible alternative explanations, not either this or that but the contributions that could be made by other factors that could contribute to climate change, such as some of the things we have mentioned already?

(*Sir John Houghton*) Yes; each time we go through an assessment we look at all the factors, we look particularly at those factors that are likely to have changed in their scientific understanding, or changed for other reasons, during that period between assessments, and weigh them against what might occur from greenhouse gases. And the process of the assessment is not just looking at the effect of carbon dioxide and methane, and so on, but it is also looking at the sun and volcanoes and dust and particles and changes in land use, and all sorts of things, and we are constantly looking at possible other reasons for climate change which may make a contribution. So we are continually reviewing the whole scene.

42. And what sort of proportionate effect are they likely to have, compared with carbon dioxide?

(*Sir John Houghton*) The range, I suppose, is 5, 10 per cent, these other contributions, the likely range; there are some areas of substantial uncertainty where the contribution might be greater, up to perhaps 30 per cent, that sort of number.

43. What areas are those?

(*Sir John Houghton*) That is to do with clouds again, and the impact of particles on clouds, in particular, it is called an indirect effect of particles on clouds.

Chairman

44. A point of clarification, Sir John. When you talk about clouds, clearly you do not mean clouds that appear on a Monday and are not there on a Tuesday, you are talking about the build-up of clouds due to some effect from earth that is making clouds denser, or more frequent, or more prevalent; when you keep on talking about how clouds can effect climate change, can you just give us an idea what you mean by that?

(*Sir John Houghton*) Let me just give you an example, which we have spent a lot of time on, actually, in recent months, in our current assessment, and that is that there is a wide range of particles that enter the atmosphere from burning of forests, from sulphur dioxide, creating sulphate particles, and so on. Those particles have not only an influence of their own on the amount of sunlight reaching the earth's surface, because they directly reflect some of that sunlight away, or absorb some of it, they also act as nuclei for the condensation of droplets in clouds. Now, if you have a lot more particles in a cloud, instead of getting a small number of large droplets you get a large number of little droplets, and the properties of the cloud, the reflectivity of a cloud, the way it interacts with the energy flows, depends on the average size of a drop and the number of drops, and so on.

45. And that could be very different in the 21st century from what it was in the 19th century?

(*Sir John Houghton*) And that could change quite a lot, particularly in more industrial parts of the world, depending on the influence of these particles. So that is a possible reason for climate change. The largest estimates that people have produced are actually quite large, maybe 40 per cent, even up to 40 per cent of possible global greenhouse warming; we do not think those big numbers probably are justified, but some people are putting up numbers of that kind. On the other hand, it can be very small. So there is a wide range of uncertainty there, and this is represented in our current document.

Chairman: That is very helpful.

Mr Beard

46. But there was climate change before the last 200 years when carbon dioxide has been building up, and quite substantial fluctuations in climate. How do you filter that out from the effects of carbon dioxide, in your predictions?

(*Sir John Houghton*) We try to establish what the reasons for those climate changes in the past have been; the big reasons, of course, for the ice ages, we know what has triggered those, and that is a variation in the earth's orbit round the sun. And we are in a warm, interglacial period at the moment; the next ice age is due in due course, perhaps in 50,000 years' time, that is the sort of timescale of the ice ages. So that is a bit beyond even the timescale of the general political operations. If you are looking at variations which occur over the period of a century then there have been variations in the past, we are not entirely sure of the reason for all of them, volcanic eruptions have been one, changes in the sun may well have been another. But those are small compared with what we expect to occur this century because of the vast increase in carbon dioxide, which is now way outside, of course, any level it has been probably for millions of years.

[**Mr Beard** *Cont*]

47. The impression, Sir John, you are giving is that when you give advice, or the IPCC gives advice, the predominance of the advice is, as you have said already, around the greenhouse effect. To what extent are these other reservations mentioned at all?

(*Sir John Houghton*) I give a lot of lectures on the subject, I talk, of course, to a whole range of people, including industry and others, and I emphasis the uncertainties too. But what I do say is that, if you are trying to create a likely scenario for the future and put probabilities on it, the probability of the climate remaining the same is very small, the probability of it being somewhere around a range of what the IPCC is talking about, that is the most likely range, the probability of it being so large that we are going to get real catastrophic disasters occurring is also very small.

48. That was not what I was getting at. I accept that those changes will happen. My question is about the origins of them, the sources of them, and you are touching on other issues, variations in cloud, variations in sun activity, volcanic eruptions. To what extent are those being brought in as factors when governments are being advised on these issues?

(*Sir John Houghton*) If we are discussing with government scientists then we raise all these points and show diagrams, and so on, which illustrate what we are saying.

49. They are brought in?

(*Sir John Houghton*) Because they are bound to ask questions about it, because, of course, some of them are raised so regularly in the media; but in any case we would do that, yes.

Dr Williams

50. Would I be right in concluding, from our session today, that it is your feeling that most of the scientific objection to the consensus is actually from vested interests within the oil/coal lobby, rather than from scientists?

(*Sir John Houghton*) Yes.

51. What is your view of the green groups in this debate, thinking of Greenpeace, Friends of the Earth; have they been generally responsible, or have they exaggerated the argument for their own purposes?

(*Sir John Houghton*) They vary from one green group to another, but some of the green groups are really very responsible. They do tend to emphasise, of course, the larger effects. On the other hand, some green groups have produced documents which are really exaggerations, with unjustified statements, saying, for instance, a statement like Hurricane Mitch is the result of global warming; it is not a statement which can be justified scientifically.

52. What about the media? Have the media given the idea, say, that the Mozambique floods are due to global warming; you have got much better television, more of it, these days, and they have tended to say that there are more incidents of extreme weather now than perhaps five or ten years ago, and, again, they tend to attribute that to global warming?

(*Sir John Houghton*) There is a tendency on the part of the media, in some of their programmes, to overemphasise, or to overillustrate the effects. We are going to get more stories, for instance, with global warming, of a kind that we are not sure about, we are not sure about more hurricanes, for instance, or more typhoons. We are sure that some sorts of storms have gone up in frequency in recent years, which is probably due to global warming, but we would be much more cautious in the statements we would make than the statements that sometimes come out from the media. On the other hand, of course, there are some media productions that also say, well, this is all rubbish, because they are relying on some of the lobby groups.

53. Moving on now. The conference in Edinburgh, a couple of weeks ago, on genetically-modified foods, chaired by Professor Krebs, came to the decision, I think, that there should be an international body set up, perhaps modelled on the IPCC, to consider this whole area of GM foods. Do you think that that is a good model?

(*Sir John Houghton*) I am with the IPCC and I tend to see its advantages, I suppose; but this is a good model. And one reason for that is, if I can just give a bit of history of the IPCC again and my involvement with it, when we began, in 1988, we had our first meeting of scientists on the issue, there were, I suppose, a significant number of scientists, good scientists, there, who said: "We don't know enough to say anything, let's keep quiet; we can't get involved in this sort of political stuff, you see, because we don't know enough to argue that." So we had a big discussion on that issue, should scientists be saying things, trying to make very responsible statements, or should scientists keep quiet; and the result of that discussion was that virtually all of them said, in the end, of course: "We've got to say what we know, and in order to say what we know we have got to discuss what we know so that we can have a debate about it". And I think what is a bit unique about the IPCC, it was helped, of course, by the international nature of the science in which we are involved anyway, there were international bodies dealing with meteorology and oceanography, and the like, which were there, so scientists were used to talking to their international counterparts, and so on; but what I think is fairly unique is that scientists have taken the trouble to try to debate amongst themselves what we know and what we do not know, because they feel responsible, and because there is a mechanism whereby the assessment can be carried out. Now in other areas of science, which are equally politically important, I do not think scientists worldwide have got together in the same way to argue about it and take the time and the trouble to try to come up with really good statements. And, I think, if we had not done what we have done, in the IPCC, we would be in a much more uncertain scene as far as climate change is concerned, just because people had not really thought about it hard enough.

54. If we bring your model to the GM foods scenario, there is some difference, as I had understood, as to whether the new body—if there was this international GM body—should be accountable to the OECD or to the World Trade Organisation; or, in your own case, you are a United Nations organisation. Do you think—it is certainly

[**Dr Williams** *Cont*]
my own view—that it is the UN umbrella that is fairest for GM foods as well; what would be your view?

(*Sir John Houghton*) The parentage of the IPCC is one UN environmental body, the UNEP, and the World Meteorological Organisation, which is a UN technical support agency, so it is strongly scientifically based because both of those bodies are strongly scientific in their ethos. I could imagine there being some difficulty with a body like the World Trade Organisation being its parent, because the influence might be such that it might not be entirely neutral. If there were scientific bodies who could, bodies like FAO, for instance, would be very interested in the GM business, and I do not know whether they could be a possible parent. Though, having said all that, I also reflect on my experience with the aviation report, which the IPCC has recently done, which was partially parented by ICAO, the international body that joins the airline industries together, and that actually was no problem, they played a sensitive, positive role, and really wanted a good report which spelled out the science in a sensible way.

Chairman

55. It could be horses for courses, could it not, really, depending on what the topic is?

(*Sir John Houghton*) And who is prepared to do it, yes.

Dr Kumar

56. Sir John, what importance do you attach to the climate change models and general circulation models in predicting and analysing climate change?

(*Sir John Houghton*) Models are very important; and they are not the only thing, observations are even more important, because if you have no observations you cannot actually make any progress. But if you are going to put the observations and the data you have together, which come from a very wide range of components of the climate aspects of it, and so on, and if you are going to try to understand mechanisms, then you need a framework in which to generate that understanding, and a model provides that framework. And the reason we need a framework is because all the processes we are talking about are non-linear processes, so there is not a simple proportionality between an increase in this and an increase in that, it is much more complicated than that. And when you have many things varying; at the same time you have to find some way of putting together the forcing factors and the responses and adding them up, and the model does that for you; you cannot do it analytically because it is too complicated to do that, it is not mathematically possible, but you can do it by using numerical methods to add together the forcing factors and add together the responses. Because we do know, we have a very good knowledge of the physical laws and the chemical laws, and, indeed, the biological ones, which operate in different parts of the climate system, and in order to add those together you need to carry it out with a tool, and the model is that tool. The model can be quite a simple thing, involving an equational tool, in its very simplest form, or it can be a much more complicated thing involving many equations and many factors in a much more complicated model.

57. How accurate are these models, would you say; is there a way of testing the accuracy of the models, that you have tested in any way?

(*Sir John Houghton*) If you make a model of the climate, the first thing it has to be able to do, of course, is to describe the current climate rather well, with the current forcing, which comes from solar radiation, and the like, it has to be able to produce a response to the diurnal cycle, with a change during the day, to the annual cycle, that is the change during the year, through the variations that occur due to things like the El Niño phenomenon, and the like, or to other factors, volcanic eruptions. And you can test the model, over different timescales, by testing how it responds to things that you know about, which have occurred already or which regularly occur, and get a very good idea of how that response might be. And, to give you an example of something which has helped, I think, to give us confidence in models, more than we had before, in 1991 there was an eruption of a volcano in Pinatubo, in the Philippines, which put out a lot of dust into the high atmosphere, which was circulated around the globe, in a fairly uniform manner, actually, cut out some solar radiation, a few per cent, the average temperature of the surface and the lower atmosphere went down by about half a degree, over a two-year period, and the models produced that response quite well. But a more stringent test from that was that, as a result of that volcanic eruption, perturbations of the climate ocurred; there was an anomaly in the regional pattern of climate change. I do not know if you remember the years 1992 and 1993 but they were particularly mild winters in western Europe and particularly cold winters in the Middle East, there was snow in Jerusalem in both those years, I think, or very cold in Jerusalem in both those years. And the climate model in Hamburg attempted to try to simulate that response, and, in fact, they simulated it reasonably successfully, not perfectly, by any means, but the major anomalies which occurred in the regional climate change, as a result of that volcanic eruption, were reasonably well simulated by the Hamburg model. So that gave us some confidence in the use of models in simulating climate change on a global scale.

58. Some people have proposed the fossil data studies, in measuring the changes in climate change; have you explored that?

(*Sir John Houghton*) Yes. There are some models, a Hadley Centre model has been used to try to simulate the climate of about 6,000 years ago, for instance, with some success, at least as good success as you can test, because the data from that period is not very good, is not perfect by any means, but at least some of the features of the climate of that period have been well simulated, and others have gone further back, actually, to parts of the last ice age, and the like, in order to test models. So models have been tested against quite different climates which have occurred during the ice age, or since the ice age.

59. And are there any reservations in the research community about these models that we have?

[**Dr Kumar** *Cont*]

(*Sir John Houghton*) There is no reservation about the fact that they are valuable and useful. There is much discussion about how certain they are and how accurate they are and how you actually establish that, in terms of the detail of climate change. Many of the models, of course, we can test models against each other, and there are, what, 20, 30, 40 elaborate, coupled ocean atmosphere models worldwide, you can compare the results from the different models. But then, of course, you would argue, and quite rightly, that many of those models have the same pedigree, some of them came from the same sources, or similar sources, they are all different in some regard, but in other regards they are very similar; so how good a test is that. And that is a question we often debate, actually, as to how well tested they can be. I think, the way our confidence has grown, however, over the last 15 years, since good models have been available, is interesting, because every time, I think, the models have improved dramatically in some technical way; there has been more confidence in the results; it is not obvious that that is going to be the case, actually.

Dr Gibson

60. Sir John, in terms of these models, you are saying that these methods have been slow to develop and critically opposing them. What needs to be done to speed that up, do you think, in terms of government intervention, support, for it?

(*Sir John Houghton*) In the modelling business, you mean?

61. Yes.

(*Sir John Houghton*) The models, of course, are always crying out for bigger computers, and that is because the finer the resolution the better result you have. They are also crying out for better observations, actually, because models do need observations with which to compare their predictions, and so better observations, actually, is also a very key aspect of the whole climate research business.

Chairman

62. Sir John, we have been grilling you now for just a minute short of an hour and ten minutes, and we have put a whole variety of questions to you, which you have answered in an admirable style, without reference to notes, or your aides, or research assistants, which you have not brought with you anyway. So we not only thank you for your contribution to our inquiry but wish to say to you how impressed we are with your very deep knowledge of this particular subject, to which, of course, you have dedicated your lifetime's activity, and that is quite apparent when we talk to you. Thank you for finding time to be with us this afternoon. We wish you well in your continued researches and endeavours in this field, and we hope that when our report is produced, in due course, you will find it of some interest—not, as I said at the very beginning, that we are looking into climate change, we are looking into scientific advice, and what you have told us this afternoon will help us enormously in preparing that report. Thank you very much indeed.

(*Sir John Houghton*) Thank you very much for inviting me. I have absolutely enjoyed coming to see you. Thank you.

Chairman: Thank you, Sir John.

WEDNESDAY 13 DECEMBER 2000

Members present:

Sir Paddy Ashdown	Dr Ashok Kumar
Dr Ian Gibson	Dr Desmond Turner
Dr Brian Iddon	Dr Alan W Williams
Dr Lynne Jones	

In the absence of the Chairman, Dr Desmond Turner was called to the Chair

Memorandum submitted by Professor David Quentin Bowen, Professor of Quaternary Geology, Department of Earth Sciences, Cardiff University

INTRODUCTION

It has long been thought by some that variability in the radiative output of the Sun may be the main driver of climate change. But because the observational record of sunspot activity only goes back a few centuries it was not possible to validate this. Recently, however, new discoveries and new analytical tools have been able to show that variability in the radiative output of the Sun coincided with climate change over the last 40,000 years—including the last century and last millennium.

EVIDENCE

1. The past radiative activity of the Sun is indicated by records of variability in the production rates of two cosmogenic isotopes Radiocarbon (^{14}C) and Beryllium 10 (^{10}Be).

2.1 Cosmogenic isotopes are produced by cosmic rays in the atmosphere. When the Sun's radiative output is high it creates a strong solar magnetic field. This effectively shields the Earth from cosmic rays to such an extent that the production rate of cosmogenic isotopes in the Earth's atmosphere is reduced. Conversely, when the Sun's radiative output is lower, production rates of ^{14}C and ^{10}Be are higher, because the solar magnetic field is weaker and cosmic ray activity in the atmosphere is increased.

2.2 Past production rates of ^{14}C (which is mixed in the atmosphere and taken up in photosynthesis) is measured from annual tree rings. Past production rates of ^{10}Be (which is rained on to ice sheet surfaces at polar latitudes where there is little defence by the Earth's magnetic field) is measured from annual layers in ice cores.

3. Variability in production rates for ^{14}C and ^{10}Be coincide with changes in climate. The ^{14}C record covers the past 8,000 years and that for ^{10}Be covers the period between 3,000 and 40,000 years ago. When production rates were low (indicating stronger radiative forcing from the Sun) the climate was warmer. When production rates were high (indicating weaker solar radiative forcing) the climate was colder and wetter. Three diagrams (overleaf) show these relationships for different periods.

4. During the twentieth century the continuously rising record of atmospheric CO_2 concentrations does not parallel the temperature record. Between about 1940 and 1970, when CO_2 was rising, global temperatures were declining. Yet during this period solar activity was also declining. The rise in temperature after 1970 coincides with stronger solar radiative forcing.

Figure 1

40,000 years of variability in ^{10}Be concentration (atoms per gram) and climatic change (from δ^{18}O oxygen isotope indictor) from annual layers of ice in the Greenland Ice Sheet Project 2 ice core (from Finkel & Nishiizumi 1997). Age scale in 1,000-year intervals from present (left) to 40,000 years ago (right).

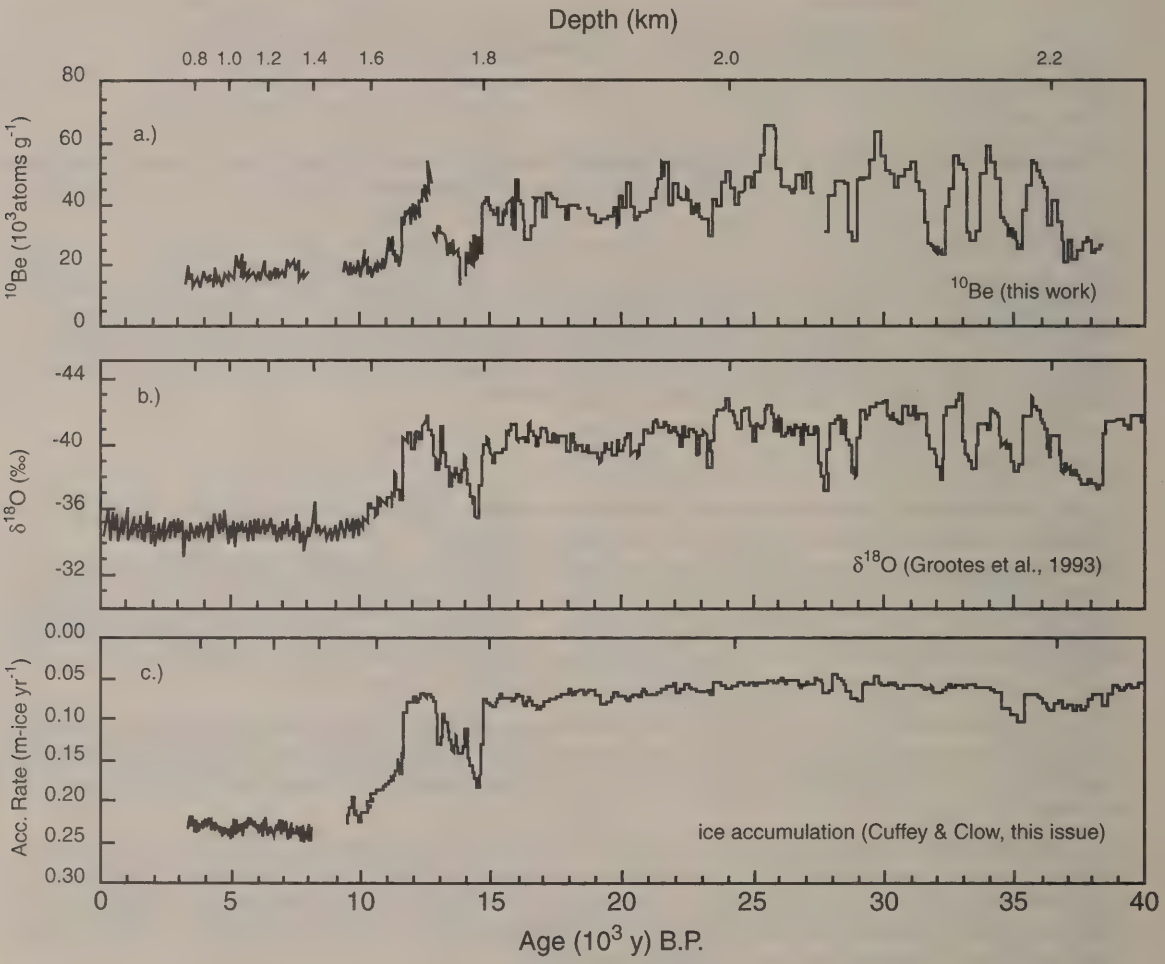


Figure 2

Greenland Ice Sheet Project 2 ^{10}Be record correlated with the tree ring records of ^{14}C, between 8,000 and 5,000 years ago (from: Stuiver & Reimer 1993).

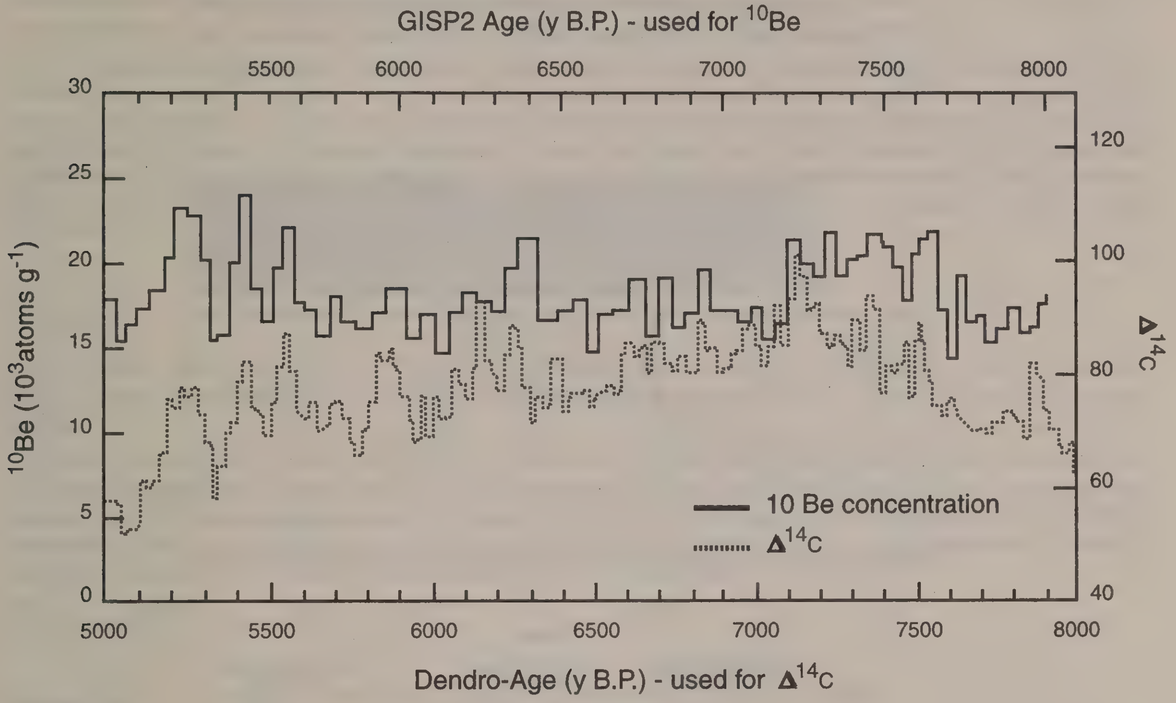


Figure 3

^{10}Be record from the Antarctic ice sheet correlated with North American and European tree ring records of ^{14}C during the last millennium (from: Bard et al. 1997).

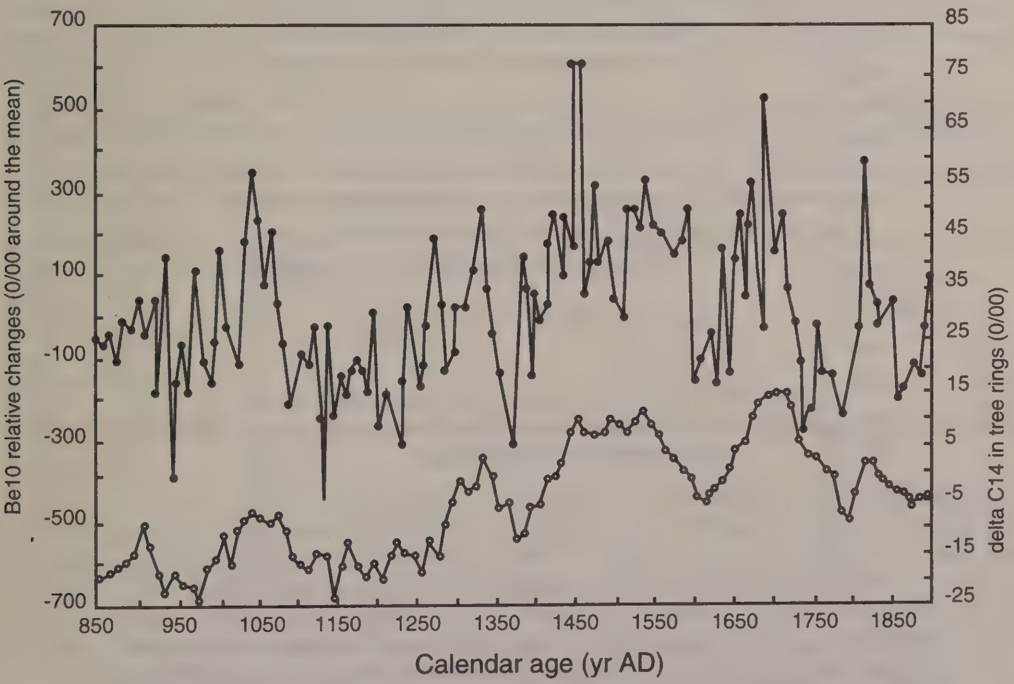
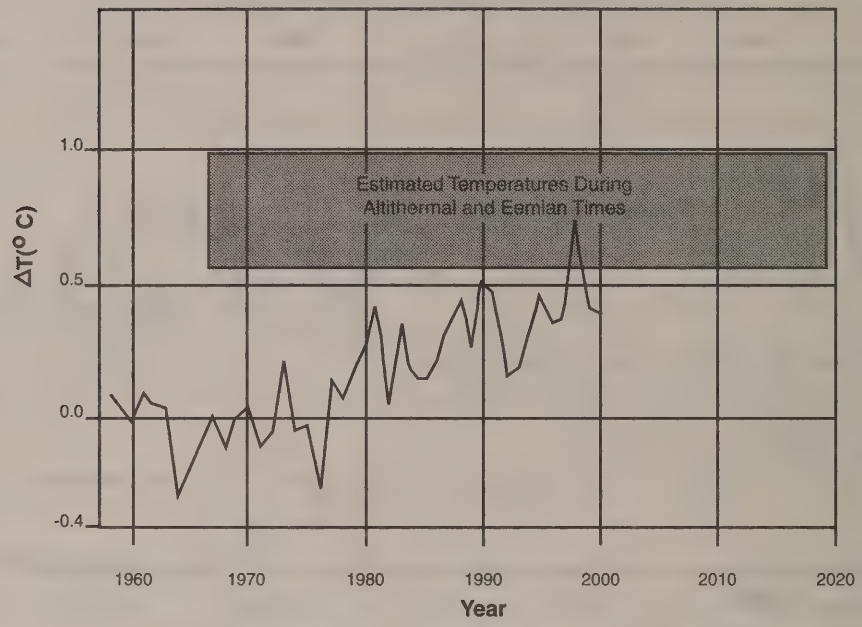


Figure 4

Annual-mean global surface temperature and band of climate variabilty for the Altithermal (Neolithic) and Last Interglacial (Eemian). From an open-letter by Jim Hansen October 2000



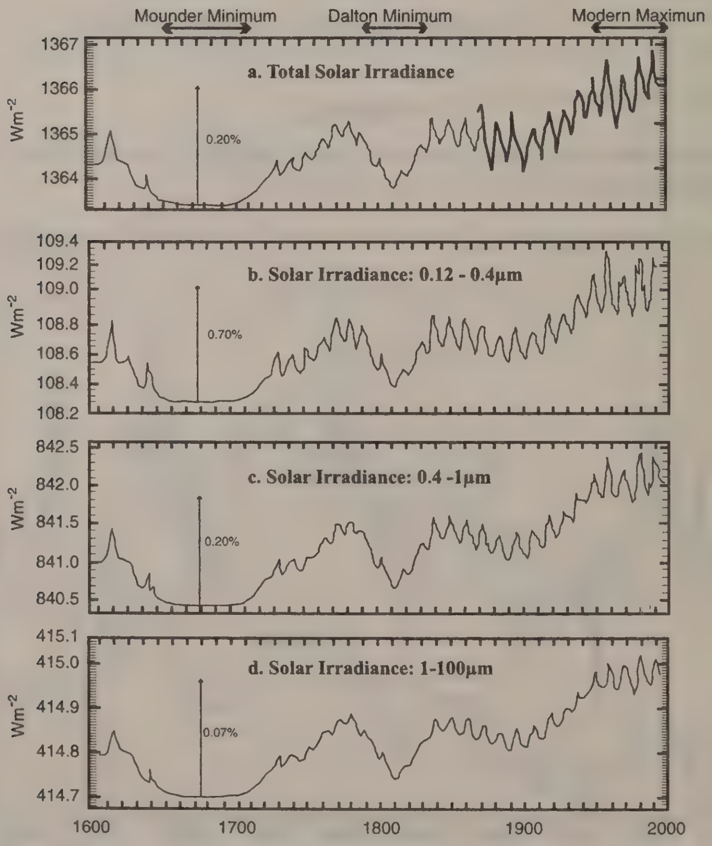


Figure 4. Compared are reconstructions of annual total irradiance in a) with spectral irradiance in broad bands from b) 0.12-0.4 µm and c) 0.41-1 µm and d) 1-100 µm. The summed bands in b), c) and d) equal the total irradiance variations in a). The shading identifies 11-year running means and the arrows show percentage increases from 1675 to the mean of cycle 22 (1986-1996). The symbols in a) are estimates of total irradiance (scaled by 0.999) determined independently by Lockwood and Stamper [1999].

Judith Lean (2000) Geophysical Research letters 27, 2425-2428

5.1 Cycles of climate change in the Greenland Ice Sheet Project 2 ice core (GISP2) occur at 6,100, 1,450 and 2,200 years. The 1,450-year cycle underpins every major climatic change for the last 110,000 years. These cycles run through the last ice age as well as the present interglacial, but were amplified during the ice age because of the Earth's unstable geographical configuration. The current interglacial, however, has been anything but stable. It could be argued that until the mechanism and origin of these cycles is understood it may not be possible to predict the future. Two main mechanisms have been proposed.

5.2 First, an ocean oscillator mechanism, popularly known as the "ocean conveyor". Bond *et al* (1999) believe this oscillator is responsible for the 1,450-year cycle which currently coincides with ongoing warming and recovery from the Little Ice Age. Second, transmission of climate changes that originate in low latitudes through the atmosphere: for example, changes in sea surface temperatures in the Tropical Pacific Ocean send global signals of climate change through the atmosphere as El Niño episodes make clear (Cane & Clement 1999). Both of these, however, may be complementary and it is plausible that both are forced by solar variability.

SUMMARY

6. It is not unreasonable to propose that the correlation of ^{14}C and ^{10}Be production rates with climate change points to variability in solar radiative forcing as the prime candidate for causing past and ongoing change.

7. Attempts to predict the future that do not take into account the facts of climate evolution on different time scales, especially the last 40,000 years, for which new evidence is available, cannot be said to address the current issue of climate change in a comprehensive way. They are, for example, not incorporated into current computer models. The relatively new discoveries outlined here may prove to be insurmountable hurdles in the quest to show a discernible human influence on climate variability.

29 January 2000

REFERENCES

Bard E, Raisbeck HM, Yiou F & Jouzel J (1997) Solar modulation of cosmogenic isotope production over the last millennium: comparison between ^{14}C and ^{10}Be records. Earth and Planetary Science Letters. 150, 453–462.

Bond GC, Showers W, Elliot M, Evans M, Lotti R, Hajdas I, Bonani G and Johnson S (1999) The North Atlantic;s 1-2 kyr Climate Rhythm: Relation to Heinrich Events, Dansgaard/Oeschger Cycles and the Little Ice Age. In: Clark PU, Webb RS, Keigwin LD (eds). Mechanisms of Global Climate Change at Millennial Time Scales. American Geophysical Union, Washington DC, 35–58.

Cane M & Clement AC (1999) A role for the tropical Pacific coupled ocean-atmosphere system on Milankovitch and millennial timescales: global impacts. In: Clark PU *et al (op cit)*. 373–383.

Finkel RC & Nishiizumi K (1997) Beryllium 10 concentrations in the Greenland Ice Sheet Project 2 ice core from 3 to 40 ka. Journal of Geophysical Research. 102 (C12), 26, 699–26, 706.

Friis-Christensen E & Lassen K (1991) Length of the Solar Cycle: an indication of solar activity closely associated with climate. Science. 254, 698–700.

Letter to the Clerk of the Committee from Professor Alan O'Neill, NERC Centre for Global Atmospheric Modelling, University of Reading

1. A possible explanation for the upward trend in the earth's temperature is natural variability of the climate system (which is known to vary on a wide range of timescales). The Centre for Global Atmospheric Modelling (CGAM) investigates natural climate variability on seasonal decadal timescales, by using advanced mathematical models of the climate system. Our results do not allow us to conclude that the observed temperature rise is entirely the result of natural variability. The weight of evidence is that the rise is connected, at least in part, to the increasing concentrations of greenhouse gases in the atmosphere.

2. CGAM makes extensive use of the climate model developed by the Hadley Centre. The model has a number of shortcomings in common with other climate models. The greatest uncertainty is probably in the treatment of clouds (and their effect on atmospheric radiation). There is considerable research worldwide to narrow this uncertainty. Increasing computer power will be essential to progress, so that climate models can represent explicitly processes that take place on small spatial scales.

3. There is a broad consensus among climate scientists that increased concentrations of greenhouse gases will contribute to global warming. These scientists also recognise the importance of natural variability, and the difficulty of disentangling natural effects from anthropogenic effects from the relatively short 100-year temperature record. There is general agreement that the anthropogenic "signal" in the temperature record is beginning to rise above the "noise" of natural climate variability. A few climate scientists (some of whom are distinguished) argue that the predictions of climate models are erroneous because important feedback processes in the natural world are misrepresented in the models (eg feedback processes involving cloud and water vapour). However, these scientists have not yet adduced credible evidence that falsifies the basic prediction of global warming.

4. Results of CGAM's research are fed into Government machinery indirectly through its contribution to the research objectives of the Hadley Centre for Climate Prediction and Research (which is supported by and reports to the DETR), and directly through specially commissioned assessment panels, eg the Stratospheric Ozone Review Group, sponsored by the DETR and the Met Office, which advises government on the effects of man-made pollution on the ozone layer. My experience is that UK scientists give Government a balanced view of the issue of global warming, based on the best science available. Alternative views are encouraged and debated when these views are expressed in terms of ideas that can, at least in principle, be tested by the scientific method. The message that there remain considerable uncertainties in our ability to predict climate accurately does not always stay in the front of people's minds. There is therefore the danger that any unexpected departure from predictions, which might be short-term, may lead to complete scepticism about the scientific basis for global warming and a relaxation of vigilance by society.

5. The Intergovernmental Panel for Climate Change has played an important role in focusing and co-ordinating climate research internationally, and helping to set the scientific agenda. IPCC reports are widely read outside the climate science community. It should play an increasingly prominent role in encouraging concerted, co-ordinated efforts to understand, portray and ultimately remedy, uncertainties and deficiencies in climate prediction models.

29 February 2000

Memorandum submitted by Manchester School of Management, University of Manchester Institute of Science and Technology (UMIST)

1. *Introduction*

The Manchester School of Management (MSM) at UMIST undertakes research into the management of climate change as part of its Environmental Management and Policy Programme. Between 1992 and 1998, Dr Simon Shackley, a lecturer in the School, conducted research on the use of climate change science in policy making in the UK, USA, Netherlands, Sweden and Germany. In 1993 he spent 4 months working at the Hadley Centre of the UK Meteorological Office to explore the science/policy interface. He has also visited the key climate modelling centres in the USA and Germany, and has attended five meetings of the Intergovernmental Panel on Climate Change (IPCC). He has written a number of papers on the subject of climate modelling, scientific assessment and the science/policy interface, copies of which can be made available to the Committee on request. (A bibliography is included at the end).

2. *Summary*

The Government has been advised of potential alternative explanations to the extent that such alternatives have been debated during dialogue with the Hadley Centre and within the scientific working group (WGI) of the IPCC. Extensive debate on alternative explanations has taken place at the IPCC due to involvement in that process of some nations and organisations which are (often for political or economic reasons) searching for alternative explanations to the consensus view that the balance of evidence suggests a discernible human influence upon global climate. Indeed the Policy Makers Summary and Technical Summary of the IPCC are much more extensively reviewed than the average paper published in a scientific journal. Associated with such a process is critical scrutiny of climate modes, since these provide much of the foundation for concern over anthropogenic climate change. The stakes around climate change are very high for many organisations and nations, hence such models are the recipients of much scrutiny—from both sides of the argument. Within the UK, the Government relies heavily upon the Hadley Centre for advice and confidence in climate models, which reflects the latter's pre-eminence in climate change research. There is probably value for the Government in hearing advice from a wider university and specialist community, at least as a "checks and balance" mechanism. Development of methods for critically appraising climate models has been rather slow, especially around uncertainty and model behaviour analysis, and such investigation could be further encouraged by Government. In the end, however, we have to accept that any knowledge or explanation of climate change will be uncertain in the short to medium (and perhaps even long) term, so the issue is not "can we prove it?", but rather "how do we decide what is the most likely explanation at the present time given scientific uncertainty?"

(A): *The extent to which the Government has been advised of potential alternative explanations, how these alternatives have been assessed and what conclusions have been drawn.*

3. *The Relevance of the Hadley Centre and the IPCC*

The provision of formal advice on the science of climate change to the Government has come primarily from Working Group 1 of the IPCC. In practice, however, the main route by which the Government has obtained its interpretation of the scientific advice is through the Hadley Centre. The Hadley Centre and WGI of the IPCC are closely identified, hence the scientific assessment and advice from both organisations is very closely aligned. The close relationship between the Hadley Centre and the WGI of the IPCC arises from three factors: the active involvement of individual Hadley Centre scientists in the WGI, hosting of the WGI secretariat within the Hadley Centre, and Sir John Houghton's chairmanship of the WGI. To some extent then, question (A) requires an investigation of whether the WGI of IPCC has considered potential alternative explanations.

4. *The Role of the Hadley Centre*

The scientists at the Hadley Centre have, on occasion, been asked by Government officials to comment on alleged alternative explanations which have been reported in the scientific and popular presses. (Examples include requests for comments on the ideas of Dr Sherwood Idso, Professor Richard Lindzen, and analysis of counter evidence of a warming trend in sensitive areas such as the polar regions, etc). On other occasions, the Research Coordinator at the Hadley Centre has volunteered information to Government officials on alternative explanations and supporting evidence which has been presented in the scientific literature, especially when such reports may find their way into the popular media. It is not known whether there is a more formal mechanism by which the Hadley Centre can communicate and explore alternative explanations with Government. More important than a formal mechanism, perhaps, is a close and cooperative relationship between officials at the Hadley Centre and those in relevant Government Departments. We have evidence that frequent face-to-face and remote communications between Government Officials and Hadley Centre scientists has many benefits for the interpretation of scientific understanding and new knowledge. This kind of relationship between climate scientists and government officials is rarely found elsewhere in the world and has been an important factor in the Government's readiness to accept and act upon the problem of climate change. The less coordinated scientific assessment process in the USA, for example, has weakened the thrust of the scientific consensus developed within the WGI of IPCC. At the same time, however, the US process reflects the more fragmented political system in that country.

5. *Role of Other Scientists*

Government has also relied, though to a lesser extent, upon advice from selected and eminent individual scientists outside of the Hadley Centre. It is possible that some greater involvement by such scientists might have raised more questions about, and produced different assessments, of alternative explanations.

6. *Extended Peer Review at the IPCC*

The WGI of the IPCC has considered and assessed alternative explanations through the process of what can be known as "extended peer review" (after Funtowicz & Ravetz). Extended peer review involves non-specialists in the assessment of scientific knowledge for policy, including Government officials and representatives of Non-Governmental Organisations such as environmental and development groups, individual companies and industrial associations. The Plenary Sessions of the WGI involved extended peer review, through suggestions and subsequent debate from national delegations and non-governmental organisations on how the text of the Policy Makers Summary and Technical Summary should be modified.

7. *Political Differences at the IPCC Encouraging Scrutiny of the Science*

The inevitably wide range of political viewpoints represented by the member countries of the IPCC makes it likely that scientific opinions which challenge the consensus viewpoint find expression during the deliberations of the IPCC. Saudi Arabia and Kuwait, for instance, have tended to take a negative stance towards the IPCC making strong scientific claims, believing that this will encourage tough emission reduction targets which will impose high costs upon their domestic economies. Such countries have tended to look to scientific arguments and explanations for climate change which negate the role of anthropogenic influences. This diversity of political interests has allowed alternative scientific viewpoints to be expressed within the IPCC. (This is an addition to the expression of dissenting voices within the full chapters of the IPCC, a practice which has increased since the IPCC first reported in 1990.) The delegates of the UK Government play an active role in the IPCC WGI Plenary sessions. Hence, they are also exposed to alternative explanations, and arguments for and against, during such deliberations, not only from UK scientists, but from an international community of scientists, policy advisors and NGOs.

8. *A Case Study from Madrid 1995*

In 1995, the IPCC WGI Plenary in Madrid arrived at the important new statement that: "The balance of evidence suggests a discernible human influence on global climate" (*Climate Change 1995: The Science of Climate Change,* CUP, Cambridge, page 4). During the Plenary there was dissent on the sentiment behind this statement from Kuwait and Saudi Arabia, who influenced the perception of the Group of 77 (less industrialised countries). As a consequence, agreement was not possible during the Plenary and the Chairman proposed that the issue be deferred to a small working group of key IPCC scientists and national delegates. This working group included Kenya, representing the G77 nations. During the three hour meeting of the working group, the different explanations of the spatial and temporal pattern of warming and cooling evident in the observations were discussed and assessed. One representative of an EU nation—a scientist by background—explicitly required the scientists to identify alternative explanations and to defend their position that the balance of evidence suggested a discernible human influence on global climate. As a consequence of this process, the Kenyan delegate was convinced of the legitimacy of the "discernible human influence" argument, and that in turn swayed the position of the G77 in favour of acceptance.

9. *Peer Review of IPCC More Thorough Than Conventional Peer Review*

It is, of course, difficult to say whether the alternative explanations have always been as thoroughly debated as they should or could have been. The above account suggests, however, that there are opportunities in the existing processes for alternatives to be expressed and discussed. Indeed, the Policy Makers Summary and Technical Summary of the IPCC reports are amongst the most scrutinised scientific documents ever produced. Unlike a scientific paper in a journal which is typically reviewed by between two and four peers, the IPCC reports (and especially the summaries) have been thoroughly reviewed and commented upon by hundreds of individuals and organisations. The introduction of an independent scientist to ensure that the lead authors of the main chapters of the forthcoming IPCC Third Assessment Review have taken proper account of the peer reviewers' comments is a welcome and necessary addition to the overall peer review process.

10. *Existence of Different Research Paradigms*

The ability to assess alternative explanations is, in part, limited by the existence of different research paradigms. Climate models make certain assumptions about what variables determine the climate, not all of which can be confirmed by evidence (Shackley *et al* 1998). (For example it is assumed by most climate modellers that the climate system, unlike the weather, is not chaotic.) Alternative explanations, which do not rely upon climate models, rely upon other untested, and often untestable, assumptions or have major gaps in their explanations. We have to accept that any knowledge or explanation of climate change will be uncertain in the short to medium term, so the issue is not "can we prove it?", but rather "how do we decide what is the most likely explanation at the present time given scientific uncertainty?" Despite all their limitations and uncertainties, climate models and their underlying physical theory, do seem to be the most robust form of knowledge for providing information on anthropogenic climate change at present. Since this judgement may change over time, given new evidence and new theories, it is vital that alternative explanations are constantly scrutinised and encouraged into the debate.

(B) *What critical appraisal there has been of models predicting climate change, increasing concentrations of carbon dioxide, and other potential drivers.*

11. *The Critical Appraisal of Climate Models*

In general, the IPCC process and its extensive peer review and extended-peer review processes, has guaranteed much critical scrutiny of climate models. For example, at the IPCC WGI Plenary in Madrid in 1995, the issue of whether and how "flux adjustment" limited the reliability of the climate change scenarios from General Circulation Models (GCMs) was raised by industrial organisations (see Shackley, *et al* 1999). In response to widespread concern from industry and many scientists about the use of flux adjustments in GCMs, climate modelling centres have worked hard to identify the model errors which result in the need for such adjustment factors. Hence, in this case, critical scrutiny has probably resulted in the modellers taking the issue more seriously than would otherwise have been the case. There seems little doubt that the critical scrutiny of climate modelling has grown with their role in providing support for the existence of anthropogenic climate change. As another example, Professor Lindzen's criticisms of how GCMs represented the upper troposphere were accepted by at least some climate modellers, who then attempted to address this problem in their models. As suggested in paragraph (9), however, the arguments over climate models will never by fully resolved as there will always be uncertainty in a highly complex, open system such as the climate. It is likely that there will always be some scientists who do not accept the projections from climate models, because they do not accept all or some of the assumptions which are necessary in constructing a climate model.

12. *Analysis of Uncertainty and Model Behaviour*

One area where there could be more scrutiny of climate models and carbon cycling models is in the analysis of uncertainty. Stochastic methods such as Monte Carlo Simulation hold out much potential for better understanding of uncertainty, but have rarely been applied to GCMs (in part for technical reasons). Other methods for better exploring the behaviour of models also deserve more attention. Parkinson & Young showed that the behaviour of a complex 23rd order non-linear simulation model of the carbon cycle could be almost exactly reproduced by a much simpler fourth order linear model (reported in Shackley et al., 1998, pages 180–182). This finding suggested that the original model included much detail that did not influence the model's behaviour. In general, rather little is known about the interactions which produce the outputs from GCMs. It is encouraging to find that the importance of uncertainty analysis using ensemble runs is now more accepted within the UK climate modelling community. Other approaches to uncertainty analysis, such as expert elicitation (eg through identification of subjective probability distributions or "Delphi" methods) have been explored much more in the USA than in the UK, and there would be value in this activity increasing in the UK.

(C) *The degree of Government agreement with scientists in relevant specialisations regarded accepted explanations of climate change.*

12. The Government follows the consensus position established by physical-science oriented climatologists. Some meteorologists take a somewhat different viewpoint especially as regards the adequacy of existing GCMs, though generally they also accept the IPCC's consensus. Even if existing GCMs are not regarded as very reliable, there are a number of other reasons for supporting the position of the IPCC (including historical observations and their correlation, physical theory and other types of climate model). A small number of climatologists from a geographical tradition are more sceptical of the ability of climate models to simulate the current climate and to produce scenarios of future change. Some of these scientists are, arguably, working in a different scientific paradigm to the climate modellers. For example, some of them believe that the climate system is too complex to be modelled using mathematics and computers. Other dissenters include a few astronomers and geologists, though again many in these disciplines accept the IPCC consensus.

23 December 1999

BIBLIOGRAPHY ON CLIMATE CHANGE SCIENCE, MODELLING AND ADVICE TO GOVERNMENT

Shackley, S (2000) "Epistemic Lifestyles in Climate Change Modelling", and Climate Change Science and Policy in the UK: "An over-identified Scientific Problem in a Context of Political Intransigence", Paul Edwards and Clark Miller (eds), Changing the Atmosphere, MIT Press, Cambridge, Mass, in print.

Shackley, S, Risbey, J, Stone, P and Wynne, B (1999) "Adjusting to Policy Expectations in Climate Change Science: An Interdisciplinary Study of Flux Adjustments in Coupled Atmosphere Ocean General Circulation Models", Climatic Change 43: 413–454.

Shackley, S (1999), "Rolling out the climate change policy lessons", Development Research Insights, Issue 30, June, 2–3.

Shackley, S, (1998) Guest Editor and "Introduction to Special Section on the Use of Models in Appraisal and Policy-Making", Impact Assessment and Project Appraisal, 16(2), 81–89.

Shackley, S, Risbey, J and Kandlikar, M (1998) "Science and the Contested Problem of Climate Change: A Tale of Two Models", Energy and Environment, 8: 112–134.

Van der Sluijs, van Eijnhoven, J, Shackley, S and Wynne, B, "Anchoring Devices in Science for Policy: The Case of Consensus Around Climate Sensitivity", Social Studies of Science, 28(2), 1998, 291–323.

Shackley, S, Young, P., Parkinson, S and Wynne, B (1998) "Uncertainty, Complexity and Concepts of Good Science in Climate Change Modelling: Are GCMs the Best Tools?", Climatic Change 38: 155–201.

Shackley, S, and Wynne, B (1997) "Global Warming Potentials: Ambiguity or Precision as an Aid to Policy?", Climate Research 8: 89–106.

Shackley, S (1997) "The Intergovernmental Panel on Climate Change: Consensual Knowledge and Global Politics", Global Environmental Change 7(1), 77–79.

Shackley, S (1997) "Trust in Models", in Michael Redclift and Graham Woodgate, The International Handbook of Environmental Sociology. Edward Elgar, Gloucester, 237–260.

Shackley, S and Wynne, B (1996) "Representing Uncertainty in Global Climate Change Science Policy: Boundary-Ordering Devices and Authority", Science, Technology and Human Values 21 (3), 275–302.

Shackley, S and Wynne, B (1995) "Global Climate Change: the Mutual Construction of an Emergent Science-Policy Domain", Science and Public Policy 22 (4), 218–230.

Examination of Witnesses

PROFESSOR DAVID QUENTIN BOWEN, Professor of Quaternary Geology, Cardiff University, PROFESSOR ALAN O'NEILL, Scientific Director, NERC Centre for Global Atmospheric Modelling, and DR SIMON SHACKLEY, Lecturer in Environmental Management and Policy, UMIST, were examined.

Dr Turner

63. Good afternoon and welcome, Professor Bowen, Professor O'Neill and Dr Shackley. This Committee's inquiry, as you know, is concerned with the field of scientific advice to Government. This Committee is not trying to resolve all the outstanding questions on climate change, causes, models, etc. None the less we are concerned with the quality of advice on those issues which goes to Government and Government's response to that advice. That is the context in which this inquiry is set. Could I begin, gentlemen, by asking you each to introduce yourselves and explain briefly how you are involved in the study of climate change. Can you mention in passing whether any of you work with the Hadley Centre or the IPCC and have any of you contributed to the peer review process which precedes the publication of IPCC reports? Incidentally, given that you do not necessarily all come from the same viewpoint, it is probably best if we make the questions fairly general unless someone wants to ask any one of you individually, so that you all feel free to contribute.

(*Professor O'Neill*) I am Alan O'Neill. I am the Director of the Centre for Global Atmospheric Modelling at the University of Reading. My involvement in climate research is that I am a climate modeller, I use complex models of the climate system to check out the models, how they perform, how they behave. I am not involved in the longer term predictions associated with increasing greenhouse gases. I used to work for the Hadley Centre; I no longer do that. I have not been involved in the peer review process for IPCC.

(*Professor Bowen*) I am David Bowen. I am Professor of Quaternary Geology in Cardiff University. My research interest over the last nearly 40 years has been with changes in the climate system on long timescales, glacials and interglacials, but recently I have been looking at changes on millennial timescales; hence my interest in giving evidence today. I have nature conservation interests. I was a member of the Nature Conservancy Council, I was a founder member of the Joint Nature Conservation Committee, and I have been Deputy Chairman of the Countryside Council for Wales for the last ten years. I have no connection with IPCC. I have no connection with the Hadley Centre and no connection with the peer review process. I am totally independent.

(*Dr Shackley*) I am a social scientist and I work at UMIST. I am also one of the research programme managers of the new National Tyndall Centre for Climate Change Research within the new national centre. My involvement in this is that I have studied the process by which Government gets and assesses scientific advice on climate change through working at the Hadley Centre for a few months and talking to a lot of scientists and policy makers involved in this both within the United Kingdom and internationally. I have attended a number of IPCC meetings, not to be a scientist assessing the reports but to look at how the scientists themselves go about the assessment process and to look at how we can assess how rigorous that process is.

64. Can I ask you, in turn, to state whether you think your views on climate change accord with the general tenor of the IPCC reports, or do you hold dissenting views?

(*Professor O'Neill*) I generally accord with the IPCC reports. I recognise that there are uncertainties in climate predictions but nevertheless I subscribe to the weight of evidence that has been advanced in IPCC.

(*Professor Bowen*) I would rather place more emphasis on uncertainty in the climate system. I would certainly like to see them take into consideration what is now definitively known about how the climate system changed in the past. In the 1996 report, for example, only three per cent of that report was devoted to past changes in climate.

(*Dr Shackley*) I think there is a difference between the policy makers' summary of the IPCC and the full report and within the full report there is a whole wealth of viewpoints and uncertainties that do not always find themselves in the policy makers' summary. In terms of the full report I think that does represent the broad range of opinion within the community.

65. Again, I have to ask you each individually: have you ever been asked for advice on climate change by the Government? How was your advice treated if it was sought? Conversely, have you ever offered the Government advice and, if so, how was that treated?

[Dr Turner *Cont*]

(*Professor O'Neill*) I have been involved in giving Government advice on an issue related mostly to climate change or global change, and that was on ozone depletion, and a panel was created, the Stratospheric Ozone Review Group, which gave advice to Government through DETR. That advice was well received and evidently played a part in the Government's position vis-a-vis phasing out the chemicals that damage the ozone layer. I have not offered unsolicited advice to the Government.

(*Professor Bowen*) Only through the agencies of non-governmental departmental bodies such as NCC and JNCC and latterly the Countryside Council for Wales. My advice on all of these occasions has been much the same, simply to state the level of uncertainty, not to take precipitate action without good cause, to understand that flood plains flood and coastal plains flood.

(*Dr Shackley*) As a social scientist I have not been asked for advice on natural science. In terms of the social science aspects of climate change these are increasingly important issues. The Government's advisory system is less well developed than it is in the natural science area that the Hadley Centre provides and I think there is a need for better channels and different sorts of channels than they have established in the natural science area.

Dr Kumar

66. Professor O'Neill, I want to explore the mathematical modelling of climate change models and you seem to be the expert on this from what you have just said to us. How good are these mathematical models and what are the limitations of these models? Do we have a grid big enough to predict this, given that there are so many variables and these are dynamic variables, patently? I wonder if you could tell us the limits and the uncertainties in your mathematical modelling work.

(*Professor O'Neill*) This is a long story and I will have to keep it brief. The system we are dealing with is a highly complex coupled system as we say, so there are many interacting components: atmosphere, ocean, land, biosphere. In the last 30 years or so we have made very considerable advances in the development of the climate models to represent basic climate variability. That has been aided by the enhancement of computer technology and also by the availability of comprehensive satellite data which we can test our models against. A nutshell statement would be that the models now show very good abilities in predicting basic elements of the variability of the climate system. However, we recognise also that there are limitations in models. We know to a good approximation the physical laws that govern many of the important processes but when we try to solve those laws we cannot do it by hand; we have to use a computer, which means that we have to approximate the equations. Because the system is so complex—it involves a range of time and space scales—we inevitably make approximations in that representation on the grid. That is part of the reason we have uncertainties in the system. For example, a comparable case would be how do we represent properly clouds in a climate system? That is pretty obvious, that clouds would be quite important in deciding how the climate is going to behave. In summary—and you can press me further on the detail—is that one bears in mind two things, that the climate models that we are using are based on basic physical laws that are tested day after day in weather forecasting. They are also evaluated on longer timescales against global data and there is a great community of people out there who do that job. There are some weaknesses in the models. I have alluded to clouds already. We also have to represent more accurately than we do the role of the oceans. There are considerable uncertainties remaining in the way land surface processes, ocean processes, biological processes, impact on climate change. There is a feedback which we need to represent.

67. That tells me how you have set up the equation and the difficulties of it but how good are your models in predicting? Do you get it right seven out of ten times, or nine out of ten times, or do you get it right absolutely?

(*Professor O'Neill*) When we say do we get it right, we have to think about how we evaluate the models. We are dealing with a system which in many respects has chaotic elements embedded in elements that are more predictable. When we test out our models we are looking at past data and we see to what extent the models capture the basic processes, the evolution, the differences, say, in one hemisphere from another. We are looking very closely at phenomena such as the Indian monsoon, the El Niño, phenomena like that, and those are the ways in which we evaluate our models. When it comes to forecasting we have to take into account that there is inherent uncertainty and unpredictability in the system, or some elements of it, and therefore evaluating the model is a bit of a tricky process because if the model does not exactly perform compared with, say, how the atmosphere evolves in a particular time, it does not mean the model is wrong. That can be just to do with the system being so complex with some unpredictable elements. That is not the same when it comes to global climate change, that is to say, the climate change brought about by man's emissions from the burning of fossil fuels. That is not to say that the models then are not capable of being used for that purpose. In fact, quite recently they have been tested quite carefully against the recent temperature record when one puts into the models the greenhouse gases, changes in solar variability, aerosols, and compared to the global temperature, and a very considerable degree of success has been achieved in doing that. It is a matter of timescales and also of exactly what you are looking at.

Dr Turner

68. Professor Bowen, do you have any observations about that? I am looking at this piece of evidence that you have supplied us with, showing that we have only this year reached temperatures of the Neolithic period.

(*Professor Bowen*) Not quite.

69. We seem to have got there in the late summer or early autumn which was the peak, and showed variations in solar radiation which have similar patterns.

[**Dr Turner** *Cont*]

(*Professor Bowen*) First of all I could say that anybody studying natural systems must at the end of the day seek to model their systems and model them mathematically. The existing climate models have improved enormously over the last five years but they are still deficient in the sense that a model cannot incorporate all aspects of reality. My colleague just referred to the lack of cloud data. I do not think we are going to have this cloud data for another three years when CLOUDSAT goes up. This will be a satellite sent up specifically for reporting cloud cover characteristics, something we have not had before, although some of the NASA satellites that went up in the late seventies had radiometers on board and did produce a certain amount of information. As far as that diagram is concerned, yes, the temperature reconstruction is very close to IPCC. It is Jim Hansen's reconstruction and Jim Hansen is the man who coined the term "global warming" when he addressed Congress in 1987, and it shows very clearly the band of climate variability that was enjoyed (in so far as we can determine that from fossil evidence) during the Neolithic period about 6,000 years ago, and also during the last interglacial 125,000 years ago. The current climate has not reached that band of variability yet, yet the boundary conditions, the seaways, the ocean passages, the mountain systems, are much the same now as they were 125,000 years ago. If one is looking for a perfect analogue for the earth in recent geological time one needs to go back to 400,000 years, and that is the time when the orbital parameters of the earth were the same as they are today, and that interglacial was warmer than at present. It was natural warmth. The sea level was higher. Towards the end of the interglacial the sea level was ten metres above present, but the difference between this interglacial and that interglacial is that, whereas this has only been running 11,500 years, that lasted 60,000 years and I suspect that the longer this interglacial lasts the higher sea level will dribble up naturally, quite apart from any human forces that will be added to that, and that is the realm of uncertainty.

Dr Kumar

70. I want to follow on, Dr Shackley, if you can comment as policy maker to ask how well can people in your field appreciate the limits of mathematical modelling? Do they appreciate that there are limits which are highlighted by Professor Bowen and how do you view it?

(*Dr Shackley*) It is an interesting question because one of the problems in the past has been that people using data from climate models perceived that it was more certain than it actually is when you are doing, say, studies of the impacts of climate change on, say, flooding or upon agriculture. I think there has been quite a lot of learning that has now happened by those scientists talking to the climate modellers and there is better understanding now that these are scenarios, they are not predictions. There is a wide range of possibilities because of uncertainty, not only in the science but also uncertainty in how much future emissions of greenhouse gases will be, which is determined by essentially economic and policy decisions.

71. Do you think in the past that policy makers relied too much on mathematical modelling in assessing climate change?

(*Dr Shackley*) There is always a temptation to resort to a mathematical model because it appears to be something very objective, very rigorous, but the evidence we have heard already suggests that validating these models is very complex. We can probably never validate them to 100 per cent. There is always going to be residual uncertainty. One consequence of that is that we need to support a plurality of methods in looking at issues like climate change. We should not just put our trust in one particular method. Because of the uncertainty, we should perhaps foster a number of competing ways of looking at the same issue, if they are of good enough scientific quality.

72. What are they?

(*Dr Shackley*) There is a range of different kinds of climate models that can be used to assess climate change. The large, complex, coupled models are only one of a family of models. You could make the argument that we have put all the research money into supporting the big, complex models, whereas we could have been supporting for far less money some of the simpler models that could provide equally useful outputs for answering particular questions.

Dr Turner

73. Given that practically the only response the Government has to climate change is to try and reduce CO_2 output, given that Professor Bowen has eloquently explained how climate change is happening without any human activity, would anyone like to comment on the effectiveness of Kyoto targets in making any actual impact on climate change, even assuming that we manage to achieve them?

(*Professor O'Neill*) Certainly it is the case that climate has changed greatly in the past quite naturally, before man walked the surface of the earth. There is no question about that. We see that in a number of records. What we are facing now is rapidity of climate change. The evidence is that that rapid climate change on a timescale of 100 years has been brought about by increases in the loading of greenhouse gases in the atmosphere. What we know also is that, even if we take considerable measures to cut or reduce the amount of greenhouse gas that we are emitting over the next 20/25 years, it takes such a long time for the gases to be expunged from the atmosphere or to be reduced to their natural levels that we are going to be committed to a measure of climate change increased by the increase in greenhouse gases. I can give you a whole host of scenarios with different outcomes according to the mathematical models, but the longer we delay the process the more we are committed to longer term climate change, if the mathematical models are to be believed, which I believe they are in this context.

(*Professor Bowen*) My feeling is that Kyoto has now passed. If I may refer to Jim Hansen, he published a paper in August. There has been a supplementary open letter and quoting the CO_2 forcing for 2050, a forcing of about three watts per square metre is involved. He has suggested that that

[**Dr Turner** *Cont*]
could be cut down to one watt per square metre if carbon dioxide is kept more or less at the present levels and we attack the other greenhouse gases, methane in particular. The rate of methane increase has been decreasing in recent years and in particular if we attack particulate matter, exhaust fumes and, coming from India above all places, particulate soot matter—it has formed a deep, optical layer over the Indian Ocean that is influencing the greenhouse effect—that is one possible solution out of it.

(*Dr Shackley*) This is partly an issue of timescale. What Jim Hansen says might be true for 2050 but the continuing emission of carbon will eventually result in a much higher rate of global warming. I think it is only valid on a relatively short timescale. On Kyoto, the key thing is that the 5.2 per cent reduction in greenhouse gas emissions from industrialised countries makes a very insignificant effect upon the climate, but it is only a first step and the Kyoto protocol was always only ever seen as being a first step in a long term process of cutting emissions far more than 5.2 per cent.

Dr Turner: The US has not even ratified that.

Dr Williams

74. Dr Shackley, you are an expert on scientific advice to government. On climate change, where is the Government getting most of its advice?

(*Dr Shackley*) It is undeniably from the Hadley Centre.

75. Is that 50 per cent, 80 per cent or 90 per cent?

(*Dr Shackley*) I would say 90 per cent. Within the Hadley Centre there is a very strong connection with the IPCC process. The Hadley provides access to the government to a much wider range of international scientists. Also, Hadley places contracts with a number of other university departments around the United Kingdom. Again, it is not just Hadley; it also extends to a much wider community.

76. The Hadley Centre is completely funded by government, is it not?

(*Dr Shackley*) I believe it is.

77. I noticed in your submission to us you said that there is a close and cooperative relationship between officials at the Hadley Centre and those in relevant government departments. "We have evidence that frequent face-to-face and remote communications between government officials and Hadley Centre scientists has many benefits for the interpretation of scientific understanding and new knowledge. This kind of relationship between climate scientists and government officials is rarely found elsewhere in the world ...". There are very close relations between government and this particular scientific advisory committee. Most advisory committees take pride in their independence from government; yet here you are saying that, because this works so closely with the government, the government listens much more to its advice.

(*Dr Shackley*) Perhaps one of the important differences is because you have the assessment of the intergovernmental panel on climate change, which is entirely separate from government. It is intergovernmental but there are so many different parties involved that no one party can influence it very much. That provides the sort of reassurance that this assessment is independent of any particular government or any particular scientific organisation. It is probably because it is connected to this international process that this close relationship functions rather well. If it was purely a national assessment, it could very easily go wrong in the way that you imply.

78. This kind of close relationship could work here but in the case of BSE or GM foods, nuclear power or some other controversial issue, where there is international back-up, there will be big changes needed.

(*Dr Shackley*) Yes.

79. Where Professor Bowen and other people have dissident views, do you feel that the mechanisms we have are so heavily dependent on Hadley that people have slightly different views, as happened with BSE, or is it the case, as with GM foods, they are out there doing their own thing, getting published but not getting noticed or considered by government?

(*Professor Bowen*) Yes. I do not believe people talk enough to each other. Different groups of different persuasions simply do not get together. For example, ideally you should have a solar physicist here today who would have told you that the climate models underestimate the amount of solar forcing by a factor of three. A moment ago I talked about watts per square metre. It does not mean much to people but three watts per metre squared is three Christmas tree light bulbs put on every square metre of the earth's surface; yet we now know that solar radiance has increased by 2.8 watts per square metre from the Little Ice Age to the present. Given my own particular persuasion, it seems to me that we simply do not talk to people. We should be talking to oceanographers and modellers.

80. Dr Shackley made a point about the international dimension in this. There are forces out there, Saudi Arabia, Kuwait, President Bush or dissenters in the United States that are looking for your kind of point of view.

(*Professor Bowen*) The best forum that exists right now is the American Geophysical Union in San Francisco but yet again I do not think it meets all the criteria that everyone is there talking with everybody else. There was a PPARC/NERC meeting in London last month looking at the sun climate links and there were just three non-solar physicists there out of 75 people. It seems to me that a conscious effort has to be put into this to obtain all shades of opinion on the definitive facts that different groups of people can produce.

81. Professor O'Neill, you are involved as well in IPCC work. What is the consensus among scientists? Is it 80 or 90 per cent likely that it is carbon dioxide and methane and these greenhouse gases and not these sun spots or whatever?

(*Professor O'Neill*) The relationship of solar variability to climate is a very challenging issue and we do not know all the answers. We know the solar connection with climate change must be important because we have had ice ages and periods in between ice ages. What is more controversial is the extent to which solar variability on a timescale of 100 or so years, which is very pertinent to us now where we are

[Dr Williams *Cont*]

seeing changes in the temperature record—that is much more controversial. Broadly speaking, 90 per cent—probably more—of scientists involved in climate research in terms of what is happening now and what could happen in the future will be of the opinion that it is associated with greenhouse gases, but the effect of the solar variability—and there is a contribution, albeit uncertain—is of rather lesser magnitude on that timescale.

82. Professor Bowen, you disagree?

(*Professor Bowen*) I do not believe science works by consensus. The only consensus in this business is that one computer model replicates more or less what the other computer model shows.

Sir Paddy Ashdown

83. Precisely on that, let me see if I can tempt Professor Bowen to a rather more brutal statement. Is it your view that the closeness of the relationship with the Hadley Centre is leading to the danger of the fact that the Government is caught in something of a fad here which is self-reinforcing or, at the very least, is insufficiently challenged by dissenting views and other scientific disciplines?

(*Professor Bowen*) I really would like some notice on such a question but perhaps by saying that you have my answer!

Sir Paddy Ashdown: I will presume yes!

Dr Jones

84. What would you do about it? You talk about the need for all the different disciplines to get together. Is not the IPCC the appropriate forum for that? Have you any suggestions as to how we improve the way that functions? What has the IPCC achieved? What do you think of the way it functions? How could it be improved?

(*Professor Bowen*) I think the IPCC in their publications have done an absolutely marvellous job of describing the climate system in its various aspects, quite magnificent. Where I am less happy and would like to see a larger range of people involved would be in some of the details that would not necessarily strengthen the position of the statement that says that greenhouse gases are causing climate change and will cause a major climate change in the future. There are distinguished scientists around the world who will say very clearly that we simply do not know and if we pretend that we do know that is the worst possible thing we could do.

(*Professor O'Neill*) I do not think we pretend we know. We recognise that there are uncertainties and chains of uncertainties. The international effort has been very much geared up to narrowing those uncertainties and removing them. I am not aware of any sense of international conspiracy because the best way for scientists to make a reputation is to break the mould and I would not hesitate to do that if I could. It is always possible to have a dissenting voice and one would encourage it. What we have to do is take the dissenting voice, see what it is based on scientifically and test out the science. That is the acid test in the end, to see whether we can explain what we see by the mechanism that is being used or by the hypothesis that is being used. I agree with Professor Bowen: I think the IPCC has done a magnificent job. It is realising more and more the importance of the role of uncertainties. I do not think people in IPCC feel that the uncertainty is going to turn around dramatically the basic tenor of the advice that has been given. One has to feel much more comfortable about the nature of the advice when some of the significant uncertainties in various parts of the system have narrowed down.

(*Dr Shackley*) We have to distinguish between different disciplines in terms of how they contribute to science and climate change. There is a group of scientists who make predictions or scenarios of future climate change using models and then there are other people who, say, do studies of historical climate change, but those people doing historical studies are not the people who are making predictions of future change. They might provide material that can be used to validate the models that are used for predictions, but a lot of these other communities who have not been so centrally involved are not actually the communities who are making the key claims in the science about the future change, which is after all what really matters in policy terms. That probably explains why there is this different arrangement of disciplines and why some have not been so involved. Amongst the scientists who are making predictions there is, as well as a common understanding of the science, also an element of a precautionary ethic in the work of, say, the IPCC in the sense that there are some values in there that we should be erring on the side of caution when it comes to issues like climate change. I would not try and pretend that this is purely driven by science. I think it is also partly driven by an emerging set of values about protecting the global environment.

85. Does it really matter? Irrespective of whether the models and predictions are accurate, based on the precautionary approach, should we not actually be doing absolutely everything we can to reduce greenhouse gases and other forms of pollution? Would the other members wish to comment on Dr Shackley's comments and that further question?

(*Professor Bowen*) Absolutely. I think we are doing that, are we not? If you look at the record of lead, for example, in Greenland ice cores since unleaded petrol has been used it has actually plummeted. If we pay attention to methane and we pay attention to aerosols in the atmosphere, I think we are paying attention to the precautionary principle but how far do you take it? How far do you take it on coastlines? How far do you take it, if you can take it any further, on flood plains? How far do you take it in certain circumstances when it is going to take a great deal of the gross national product? I hesitate to introduce a moral point at this stage but at a time when most of the world's people are living in absolute destitution might the money not be better spent in raising their standard of living?

86. Which money is this? The money that is being spent on what?

(*Professor Bowen*) The money that is being spent to a large extent on negating perceived aspects of climate change, various defence schemes.

[Dr Jones *Cont*]

87. What about changed behaviour? All the research is used by Government to develop their policy and obviously the issue is how far governments should go to restrict CO_2 emissions and so on which could result in considerable changes in lifestyle, which could have financially beneficial effects, not just cost money.

(*Professor Bowen*) This is a political matter. It is really up to what the voter can take in such situations.

88. They want a prop, if you like, in taking those difficult political decisions.

(*Professor Bowen*) I think the things we are talking about are so esoteric as far as the public are concerned that they are either unable or unwilling to evaluate them and it seems to me therefore that you would never convince the public to stump up their pound in their own pockets in this quest.

Dr Williams

89. The British public, the German public, the European public, has accepted Kyoto, have accepted carbon dioxide, have accepted global warming and are very environment sensitive. The American public is not but perhaps their politicians are. Could we just talk about unleaded petrol? The great thing about unleaded petrol, or the problem of lead pollution, was that there was a technical solution, a ready economic one, but in this case it is much more intractable. I challenge your pessimism about the understanding and the desire of the European public to have something done.

(*Professor Bowen*) I did not come here to talk about Kyoto; I came here to talk about climate systems.

Dr Iddon

90. I want to make sure that we have got all the uncertainties on the table. I have written down— while we have been talking uncertainties, about the modelling experiments which after all are experiments, and there must be various models being explored there, so that is one possible uncertainty - I have written down the question: have we taken solar sources into account adequately, and I have put a question mark on greenhouse gas emissions? Are we, for example, taking into account all the forest fires that there are in a year, for example? I read a statement recently that all the forest fires in a year put out more dioxins in one year than man has ever put out synthetically himself or herself. Are we not tinkering at the edges with carbon dioxide when we look at the forest fires that occurred last year? Are we taking that uncertainty into account? There are three uncertainties. Could you give us any more uncertainties that we should be considering in this debate?

(*Professor Bowen*) If you would like a paradigm of uncertainties, I think we are currently aware of a whole variety of forcing functions as far as the climate is concerned, some of them acting at different cycles. These are the pacemakers, and very often we can see the end product of these forcing functions, but in between there is a great black box. We see the forcing going in and what comes out very often amplifies the forcing that has gone in, so there are powerful non-linear feedbacks operating within the system. These are uncertainties that fall into the realm of the unknowability at the present time and will remain in that realm of unknowability for a long time. It is frequently said, for example, that we know what caused the ice ages. We do not know what caused the ice ages. We know that the forcing function is the pacemaker to orbital changes of the earth around the sun and we know what the output is. It is the geological record of ice ages, but the record of ice ages doubles the input that goes into that system. We simply do not know how the atmosphere, the cryosphere, the world of ice and snow, the greenhouse gas system, the ocean circulation, work; we do not have an adequate handle on these. It is only through increased high quality data and modelling of that data that we shall ever get to that position.

91. Do either of your colleagues want to add to that?

(*Professor O'Neill*) It is an interesting question about whether or not we have an adequate knowledge. I would certainly agree with you that there remain uncertainties in every corner we look at. In terms of what is likely to be the outcome of pumping greenhouse gases into the atmosphere for the next 50 to 100 years I am less pessimistic in the sense that we do not have an adequate knowledge of all these factors. I would add a few areas of uncertainty. We are going to witness one evolution of the planet in the next 50 years. If we were to set up lots of different worlds under pretty similar conditions each of these world would evolve slightly differently, so we would get natural variability. It could well be for example—let me be specific—that in the next 30 years we will see a decline in temperature. That would not in any shape or form rule out the underlying notion that there is a longer term trend in the temperature record because we have got superimposed on the forcing of the greenhouse gases natural variability in the system. That is one area of uncertainty. Another area of uncertainty I would say is the response of the biosphere to changing climate. There are very significant sources of things like carbon which are quite natural and you have mentioned that point already. As climate changes vegetation will inevitably change. We are talking about changes in quite rapid timescales again. It could well be, and some calculations suggest, that changes in the natural carbon cycle may exacerbate what man is doing in that area. I would caution that there are lots of uncertainties in that one. Possibly one of the biggest uncertainties is how human beings themselves will respond. This is ultimately the fulcrum process. We are part of the natural system in some respects, and how we respond to what we see happening, what the predictions will be and how the nations of the world get together or do not is going to be a major area of uncertainty for climate modelling.

(*Dr Shackley*) The uncertainty I see in a sense is the bread and butter of what scientists do and scientists love talking about uncertainty and can sometimes give the impression that that is all there is. What is actually quite remarkable about the climate change is the degree of certainty that has been formed

[**Dr Iddon** *Cont*]
internationally through the IPCC, through a very rigorous process of review. Scientists will always find uncertainties, but if you push them and say, "Do you really think that greenhouse gas emissions will cause global temperatures to increase within a range of 1.5 to 4.5°C for the doubling of CO_2?", then the vast majority of those scientists will say that they do believe that. At a certain point when this uncertainty is not affecting their basic judgment the science of climate change is rather sound and is quite well understood.

92. Do you feel that the policy makers that you advise, and other scientists advise, are capable of understanding all the uncertainties in the argument, or do you find that they are putting pressure on you to provide black and white answers to their questions?

(*Dr Shackley*) I think the policy system does tend to prefer certainty and finds uncertainty difficult to deal with. That is often because the amount of time you have to invest to understand the significance about uncertainty is rather high and most policy makers simply do not have the time so they prefer the story to be told without excessive mention of uncertainty and relying on scientists' judgment. That is where the IPCC has been very useful because it has provided an international forum where the world's best scientists can actually have this discussion and they are all coming from their own particular viewpoints, their own organisations, but additionally it is including governmental representatives, representatives of industry and representatives of environmental groups, so you have got all these different perspectives that have to be taken account of in how that knowledge is distilled and then presented without excessive mention of uncertainty. It is rather an interesting process by which this distillation does not just involve scientists and its strength is that it is being reviewed by the wider community.

93. I might throw a naughty question in here which is not on the sheet, and that is: why does not the American Government listen to its scientists?

(*Professor Bowen*) Who says they do not? I think a great deal of advice does go to the American Government and this is quite independent of the so-called industrial interests that are supposedly financing some of the people. I think the quality of advice that goes to the Government from NASA, for example, from the NSF, from various high powered institutions like the Lawrence Livermore Lab, Berkeley, California, is very high and I think that the calibre of many congressmen in scientific terms is also quite high.

Dr Turner: We have met one of them that possibly was not, but perhaps that is colouring the question.

Dr Jones: The member of the committee that we met when we were in the States a couple of years ago completely and utterly denied that climate change was happening.

Dr Iddon

94. What you are saying is that the advice is there, obviously the Government is listening, but the industrial lobby is preventing them from taking any action?

(*Professor Bowen*) No, I am not saying that at all. I do not know if my colleagues would agree with me.

95. I am sorry if I misrepresented you.

(*Professor Bowen*) In terms of manpower resources that are devoted to this issue the United States far eclipses what is being invested in the British Isles. Most of the front line action is taking place there, not in this country. France is slowly catching up but it is the US. It is a massive effort.

Dr Williams

96. But is it a massive effort in these negative areas that you are involved in rather than the modelling and so on?

(*Professor Bowen*) No. I think you will find at least 50 per cent of the scientists who write the IPCC reports take the position that there will be enhanced global warming in the future. I do not think that is the case at all.

Dr Jones

97. Taking up what Dr Shackley was saying, do you consider that the IPCC as a process is a good model for scientific advice to government in other areas? Is there not a danger that they are too consensual? Peer review was mentioned. How satisfied are you that those invited to participate in peer review are sufficiently diverse?

(*Dr Shackley*) I think it is a good model for some issues. Obviously, it arose because it is a global issue. We are talking about systems that are connected globally so to do any science or assessment you have to start from the global level. There are many other issues you do not have to start at the global level. You can start at the local level and work in a range of scales. I do not think automatically it would work for political reasons for certain issues but when you are talking about—

98. One issue you suggested was genetically modified organisms, for example.

(*Dr Shackley*) I have not thought that through but I can see the value of some sort of international assessment. You have to recognise that the climate change work builds upon at least three decades of dedicated scientific effort. As Professor Bowen says, the US has put huge amounts of resource and in a sense allowed the capacity to be there for the process. I am not sure if in GMOs that is the case. On your point about diversity, I have been to IPCC meetings where what typically happens is that the industrial lobby of the United States will be looking for any signs of weakness in the science and any uncertainties which it can use to try and reduce or weaken the argument. They will send somebody over to the Kuwait and Saudi Arabia delegation in order to get the question asked within the plenary. This is quite an effective mechanism by which any uncertainties or questions of credibility of the science are seized upon and communicated rather quickly to the political

[Dr Jones *Cont*]
faction which might find this helpful. That is a legitimate process within the IPCC and they live with that. They have to have it out in discussion, which is why their meetings tend to last until the early hours.

Dr Williams

99. Professor O'Neill, I would like to ask you about the Hadley Centre climate modelling. It has a lot of mathematicians and physicists and an international reputation for its work, but does it have enough biologists and other social scientists?

(*Professor O'Neill*) No. That is an area that I believe the Hadley Centre recognises increasingly, although I would not want to speak for them: the importance of those disciplines in getting the full picture of how climate is likely to change. They are moving slowly in that direction. There is a large community of extremely capable biologists who have relevant knowledge in the United Kingdom and in Europe. If I was in the position of encouraging them, I would encourage them to tap into that knowledge base.

100. The Hague conference was very much about carbon sinks and their role. Do you think that in European research, our contribution to the IPCC, we have tended not to have researched enough into that area or given it sufficient recognition?

(*Professor O'Neill*) I would tend to agree with you. It is an area that we are recognising is important. There are important feedbacks that need to be brought into these climate models. The fact is that science evolves. It is not an oversight. We are starting to appreciate more and more the potential for these feedbacks and the importance of representing them. If you go back, say, ten years, it is only in the last decade or so that we have attempted to represent properly the role of oceans in these climate models. That is absolutely fundamental. We have to realise that we are involved in a very rapidly evolving and developing science.

101. 20 or 30 years ago, of the coal, oil gas and all fossil fuels that have been used in the last century or whatever, the rise in carbon dioxide concentrations in the atmosphere would be much greater were it not for the amount already absorbed by the world's forests and oceans. It would be twice the rise that it has been. That is the case, is it?

(*Professor O'Neill*) I do not know if it is a factor of two exactly but certainly there would have been much more carbon dioxide in the atmosphere it had not been for the natural absorption.

102. In that Hague compromise, do you have a feeling overnight, and since then, that there is a compromise there and what is the shape of that?

(*Professor O'Neill*) It is difficult because this is very much an area of considerable uncertainty. If we are talking about the role of, say, vegetation and planting forests as a way of absorbing the excess carbon dioxide that we are emitting, that could be slightly dangerous in the longer term because the existence of climate change could end up with vegetation which currently acts as a carbon dioxide sink under present conditions and could then become a source rather precipitously.

103. How?

(*Professor O'Neill*) For example, if we have changes in climate zones and vegetation dies away—it is not able to rapidly respond to a change of climate—or the type of vegetation that exists is a less strong carbon sink, the end result of that is that more carbon dioxide is released into the atmosphere.

104. The higher is the per cent of tree cover of the land mass, the greater the concentration of carbon dioxide.

(*Professor O'Neill*) If everything else is static. The problem also is that in between putting large bands of forest changes the reflectivity of the earth and the forests tend to be darker and they tend to absorb more solar radiation. When we are talking about the land surface by vegetation feedback in the climate, this is precisely the area that we do not know anything like enough about.

105. Dr Shackley, as a social scientist, are social sciences adequately reflected in the work of the Hadley Centre?

(*Dr Shackley*) No. They do not do any social science work. They rely on other social scientists, for example, to provide them with scenarios of future greenhouse gas emissions from different regions of the world, making different assumptions about economic growth rates or population change. They use other people's social science. Their mission is not within social science. Within the new Tyndall Centre that I am part of, part of the mission of that is to integrate social science much more effectively into the existing natural science. We will be working with the Hadley Centre to aim to do that.

Dr Gibson

106. You have indicated there is not a lot of coherence; there are a lot of things missing and people doing different things in the way that academics do for the great fives and five stars and so on and this is full of five stars all doing their own thing, competing against each other. Do you think there would be a major advance if we worked together? People are getting a bit fed up with you crying wolf about global warming. It can be said too many times. Would a coherent science policy reflect any way of getting the message over much more substantially in a social context but also in the academic arena of scientific research as well? I am aware of the stuff coming from Norwich about to heck with it all; just let the coastline disappear. Why bother? It is too much money. Just do not let people build their houses too close to it. Build them in Norwich, not on the coast. People are getting rather fed up. It has been going on a long time. How can we get the arguments that you are portraying, and obviously care about, over in a coherent way in terms of selecting a science? You have said there are some gaps. What can we do to bring it all together in terms of a really big scientific message that looks coherent and not just groups competing with each other?

(*Professor Bowen*) It is an extremely tall order. Had it been readily possible, I suspect it would have been done by now. Turning again to the States, people there are not anything like as bothered about global warming as they are in this country. I cannot tell you what the reasons might be, but they are more

[**Dr Gibson** *Cont*]

relaxed about things. Maybe there is something in that system that can help us, but yes, as one talks to ordinary people these days, people are getting fed up with it and they seem to sense that something is wrong. It is the same story and there is no great step forward to elaborate it.

107. Let us hear the social scientist tell us what is wrong.

(*Dr Shackley*) I am not sure I agree that there is anything wrong in having different messages and having some diversity because I think that encourages debate. It is useful to have those inputs. There is a danger if we try and coordinate things too much and try to create a single message. What if the message is the wrong one? Can we be sure that it is the right message? I think you will find there is disagreement about what the message should be.

108. What is the message you have for us?

(*Dr Shackley*) My message would be that climate changes the global scale. There is a surprisingly high level of confidence amongst the scientific community that climate change will occur on a global scale. When you go down to other scales like the regional scale and the national scale, the science is simply much more uncertain so it is much more difficult to start to attribute particular extreme events to the general climate change. Nevertheless, over the time periods we are talking about, it is likely that climate change will begin to influence climate at these local levels. We might as well act in ways that have benefits in terms of preparing ourselves for climate change but also have other benefits for other reasons. You mention the coastline. It is not just because of climate change that people—including noticeably the Environment Agency—are very keen on managed realignment. There are many other benefits around managed realignment. I think we have to be looking at responses that combine a number of different policy objectives and not just rely on climate change as the sole justification unless we have very good scientific evidence.

109. Can you think of one piece of scientific evidence that would do it? That is a terrible thing for scientists to ever answer but is there one thing, in your wildest moments, if it was proven, that would do it and convince governments to sit up and take notice across the world. We are not convinced that floods are due to all that really. What would really make a difference? Is it just too long term and too imprecise?

(*Professor O'Neill*) The fact that you are not convinced about the recent floods and global warming is absolutely fine because neither am I. You could not possibly say that that is the case. What we would be looking to see is that in the longer run of things there would be increased frequency of these kinds of events. It is very hard to pick on one single thing. What we are getting is from different sorts of quarters, different pieces of evidence fitting together into the big jig-saw puzzle. I do not see any missing corner piece that would absolutely clinch it. It is not likely that the west Antarctic ice sheet is going to fall off its ledge and drop into the ocean. I do not think there are things like that. It is mounting, cumulative evidence. Two things strike me in terms of public perception. One is the longer term in which it takes for the real signal of this global warming to emerge from the natural variability. Secondly, it is because perhaps wrongly people have been conditioned to the notion that scientists can talk about systems with a degree of certainty. It may be with some control systems we can do that. When we talk about the natural system, there is uncertainty inherent in that. It is not just about the fact that we do not know enough about the equations or we cannot stick them in the computer well enough. We are dealing with complex systems and frankly, when I went to university, I was not trained to deal with these kinds of things. It is a new dialogue we have to get with the public to appreciate how to balance the uncertainties that we are happy to talk about with the balance of evidence which is saying yes, there is something serious going on.

Dr Williams

110. I am disappointed that you are so defensive. If I was working in your field full time and knew as much about it as you do, I would want to be reassured about the Arctic ice and so on. We did that for the ozone problem. Nobody has been there or found any effects of it and yet people out there, politicians, were persuaded about CFCs. There is a big consensus about it. Why are you not on soap boxes attempting to persuade the people or the politicians themselves?

(*Professor O'Neill*) I do not think we are being defensive. I think we are trying to present the evidence with the right balance. The example of the ozone hole is a nice one because in fact this is a good example where scientists did work very hard to pin down the science. There was a huge amount of scepticism about this. People say, "Oh, it is natural. Look at the scientists coming up with this nonsense", but scientists have pinned it down. In this particular case the nations of the world did act and phased out the damaging CFCs and the United States was included in that. This was a happy circumstance in which there was a relatively straightforward technological solution. Of course the solution was that there were replacement chemicals and other things you could do. The problem with greenhouse warming is that fossil fuels are still the basis of energy production. There is no easy solution. The other point is, and this comes back to this soap box idea of shouting it from the rooftops, that we always have to recognise that one piece of evidence like the melting of the sea ice to some extent is not enough. That could occur naturally. It is the pattern of changes and the mounting evidence that comes with it, whereas the ozone hole is much more specific, it opens up every spring and then closes again. There are greater uncertainties I would say and the role of natural variability is much more dominant.

111. But in terms of the general public out there—they take their views from Friends of the Earth and Greenpeace, rather than from the Labour Party or from MPs or, unfortunately, from scientists who know a hundred times as much as those members of Greenpeace in terms of the earth.

(*Professor O'Neill*) Yes.

[Dr Williams *Cont*]

(*Professor Bowen*) With respect to the melting ice in the Arctic, I do think the public are now aware that there is such a thing as the North Atlantic oscillation and it has been stuck in its present mode for the last 20 years and warm air is being pumped up into the Arctic. That could switch suddenly and as we are having mild, wet winters now, they could switch to the Mediterranean and we could have very cold winters. If you took it on a larger scale, possibly as a result of enhanced greenhouse gases which would produce greater run-off in the North Atlantic, you might produce fresh water which would freshen the surface of the ocean and would slow down the thermohaline circulation which pumps water up there.

112. You are telling me that you have got a ready explanation for global warming for the Arctic melting?

(*Professor Bowen*) Yes, an alternative to global warming.

Dr Turner

113. Would it be fair to gather from what you have been telling us, both verbally and in writing, that having paleoclimatic evidence of global warming which is going on anyway now, overlaid with man's activities, makes it very difficult to disentangle the two processes and do you have any confidence in scientists' ability ever to predict it with any degree of accuracy or of governments to be able to respond to the advice if anyone can ever agree on what it should be?

(*Professor Bowen*) What you are really asking me is to disentangle natural variability from anthropogenic forcing on which the IPCC said in 1996 that they could detect a discernible human influence. It seems to me that until we understand all the forcing functions, until we understand all the processes and the feedbacks, I do not honestly think that we are going to be able to say confidently what, for example, the global temperature will be in the middle of the next century.

Dr Iddon

114. I just want to make a quick reference to volcanoes. The Geological Society have suggested that large volcanic eruptions can have a significant cooling effect on weather and climate. To your knowledge has this been addressed adequately in the debate?

(*Professor O'Neill*) I think there is ample evidence that the eruption of volcanoes and the aerosols they release can have an effect on climate. We detected it in the eighties with satellite data. The thing is that these aerosols released from volcanoes tend not to reside that long in the atmosphere so we can represent if you like an ambient level of natural aerosols, and in fact in doing that we have got a much better agreement with the climate models with the recent temperature record than we had when we did not do that. I do not think it is something we have forgotten about. Again, it is by no means enough to account for what we have seen. Call that a natural forcing if you like, and that will tend to give us a climate cooling typically, whereas what we are seeing is a warming. We need other things to get that result.

Dr Gibson

115. If there were one thing you could tell the Government to do what would it be, each in turn? I could give you five but what would be the most important thing to manage climate change as far as the Government is concerned? We have had lots of talk but what could we do that would be effective and win the support of the public?

(*Professor O'Neill*) Try to recognise that there is a real threat of rapid climate change even acknowledging yet again the magic word "uncertainty" and that where we can institute changes in the way we live and the way we operate there are other longer lasting benefits, in other words a no risk strategy that we should inevitably try to go that way because when there are increases in energy efficiency there are knock-on benefits and what one then gets is sustainability.

(*Professor Bowen*) Energy efficiency, cut down ruthlessly on all pollutants, and I do not include carbon dioxide as a pollutant. Carbon dioxide is an essential part of photosynthesis and the reason for our being here. If government did concentrate on those things which are eminently attainable, this would be putting the precautionary principle into action at a reasonable level.

(*Dr Shackley*) I agree with the other two in the sense that we are now in the domain of solutions to the problem of climate change. The debate has moved on. The Hague aside, the Kyoto protocol is not going to go away. There will be negotiations. Even if the US are not involved, it can still be ratified if the industrialised countries get their act together. Business is taking this incredibly seriously now, including in the United States. We are moving into a world which will economically and socially change because of climate change, even if climate change is not manifest in the immediate future. The implication of that is what the government is already doing and it needs to continue to do that in relation to the climate change levy and emissions trading schemes. There is a lot of exciting development in the new Carbon Trust which is using some of the money from the levy to support new energy technologies, renewable energy, ways of decarbonising the energy system as well as storage of carbon by forests. There is a lot of opportunity for captured carbon storage in disused oil and gas fields, for example, and there are huge opportunities for business as well. These are the areas that I think government should continue to support.

Dr Turner: Gentlemen, thank you very much. I apologise that we have run slightly over time. It is the loquacity of our members, I am afraid. Thank you very much.

WEDNESDAY 20 DECEMBER 2000

Members present:

Dr Michael Clark, in the Chair

Dr Ian Gibson	Dr Desmond Turner
Dr Brian Iddon	Dr Alan W Williams
Dr Lynne Jones	

Memorandum submitted by the Department of the Environment, Transport and the Regions

1. The Department welcomes this inquiry by the Select Committee. Man-made climate change is one of the greatest challenges facing mankind. The international scientific community have evolved one of the most thorough and ambitious systems for assessing the science of climate, and the UK science base and the Meteorological Office have played a key role in its work.

Responsibilities Within the UK

2. Within Government, the Department of the Environment, Transport and the Regions takes the lead on policy on combating man-made climate change. Working with other Departments and Agencies it represents the UK at international fora including the Intergovernmental Panel on Climate Change (IPCC). The Chief Executive of the Met Office, supported by the Director of the Hadley Centre, provides specific advice on climate matters including climate change modelling. The Department is able to draw on the UK science base for advice on climate change impacts. Overall a high level co-ordination of UK research on climate change and other global environmental issues is undertaken by the Inter-Agency Committee on Global Environmental Change. This committee is currently being reviewed by the Office of Science and Technology, DTI.

3. However the Department has recognised from the beginning that global warming is a global problem and that it would require an international scientific consensus before international action could be taken. For that reason the UK was one of the founder nations of the IPCC. DETR has given substantial financial support to the work of the Panel and has supported the chair of the scientific assessment working group, Sir John Houghton. The IPCC is now the pre-eminent source of advice on climate change science.

4. DETR also supports, through its research programme, the assessment and prediction of climate change, largely through global climate modelling at the Hadley Centre. While the Hadley Centre is widely recognised as having built the world's leading climate change model, the Department assures the quality of the programme through an independent Science Review Group of the country's leading experts. The Department also commissions, from the University of East Anglia's (UEA) Climatic Research Unit (CRU), independent assessments of the output of the model against current meteorological data sets. A 10-year independent review of the Hadley Centre has just been commissioned by the DETR and MoD.

5. The Department receives frequent advice from its contractors, particularly the Hadley Centre, on its research results and current developments in the science. It also seeks advice from time to time through the wider science base.

IPCC

6. The IPCC was formed in 1988 under the auspices of WMO and UNEP to assess the current state of knowledge on climate change. It is independent of the UN Framework Convention on Climate Change (UNFCCC) though its work plan relates to the programme of the Convention. The IPCC currently works through three working groups, each with shared chairs. The scientific assessment working group (Working Group I) (WGI)) is the one of most direct relevance to the Committee's inquiry and is chaired by Sir John Houghton and Professor Ding Yihui of China. It is supported by a Secretariat located at the Hadley Centre.

7. The IPCC commissions lead authors to provide assessment of research published in the peer reviewed scientific literature. Those assessments must cover the full range of evidence and interpretations. The assessments are then open to peer review. The IPCC WGI peer review process currently involves about a thousand experts world-wide. The IPCC WGI then meets in full (usually about 100 nations are involved) to agree the policy makers summary to the set of authored chapters. Published IPCC reports are subsequently considered by the UNFCCC. The IPCC's approach fully accords with best practice in scientific assessments, in particular with guidance on *The Use of Scientific Advice in Policy Making,* "The May Guidelines".

8. The remainder of this memorandum addresses the Committee's specific questions. The committee will already have received a memorandum from the Meteorological Office on man-made climate change science, and our response takes this into account.

How and from whom does the Government receive scientific advice on climate change? Which of these are the principal sources?

9. The principal source of advice is the reports of the IPCC. These remain the definitive analysis of the global scientific literature. Advice on the significance of scientific evidence emerging between IPCC assessments is provided primarily by the Met Office, through the Hadley Centre, and by other research institutes and universities. For assessing regional impacts of climate change the Government is advised by a number of world leading centres (eg the UEA, the Environmental Change Institute (ECI) at Oxford University, the Institute of Terrestrial Ecology and the Institute of Hydrology). The Department's independent review group, the Climate Change Impacts Review Group, published and assessment of the impacts on the UK in 1996. The UK Climate Impacts Programme, with a secretariat at the ECI, seeks to involve a wide range of stakeholders in the process of assessing and responding to the potential impacts of climate change in the UK.

How is conflicting advice evaluated and verified?

10. The IPCC draws on evidence that has been peer reviewed. It provides assessments of competing hypotheses. Where it is possible to conclude between hypothesis on the basis of current evidence IPCC will do so. Otherwise it will attempt to judge the weight that can be attached to alternative explanations. To facilitate this process DETR supported workshops where scientists can meet to review the strength of their respective points of view and identify experiments or analysis that could decide between them. The Department has also commissioned reports to be published in the peer reviewed literature reviewing specific problems. This has included reviews of solar effects and the stability of the Western Antarctic Ice Sheet.

What is your understanding of potential alternative explanations for the upward trend in earth temperatures other than increasing concentrations of CO_2?

11. These have been reviewed extensively by the IPCC, and are covered in the Met Office Memorandum. The explanations are not necessarily mutually exclusive. The important issue for policy is to assess the likely contribution of man-made emissions to the observed and likely future rise in global temperatures

How does the Government assess alternative explanations and what conclusions have been drawn regarding their validity?

12. This is principally a matter for the IPCC. The role of Governments is to ensure that the assessment is undertaken to the highest standards. The IPCC procedures have been developed drawing on best practice in Europe and elsewhere, including the *May Guidelines*. Alternative explanations for the rise in global temperatures were explored extensively in the second report and will be covered more fully in the third report. It should be noted that the Hadley Centre programme has a significant component which addresses this question.

How does the Government assess the validity of various climate change models such as that developed by the Hadley Centre of the Meteorological Office? What methodology has been developed for critical appraisal of climate change models and who conducts such appraisals on behalf of the Government?

13. The Hadley Centre was established in 1990 specifically to:

- be a world-leading institution in order to provide the government with the most up-to-date advice on all aspects of natural and man-made climate change;
- provide the scientific basis for UNFCCC negotiations;
- act as a national focus for climate change research in the UK; and
- provide timely, authoritative contributions to international scientific assessments, including those of the IPCC.

14. The Hadley Centre's work programme is agreed in advance between the Centre's experts and DETR officials; it is carefully defined with deliverables due on agreed dates. The Hadley Centre's programme is kept under review by an independent panel of scientists.

15. It is important to understand the origins and pedigree of the Hadley Centre's model. Because of its origins as a weather forecasting model, its dynamics have been rigorously tested against the need to produce accurate weather forecasts. However, the model has a much more comprehensive treatment of physical processes than weather forecasting models and some climate model developments have led to improvements in weather forecasts. The Hadley Centre continues to benefit from improvements in the dynamics undertaken by the Met Office for forecasting purposes. The Hadley Centre's model is the choice of many workers outside the Hadley Centre; for instance the NERC's UGAMP (Universities Global Atmospheric Modelling Programme) uses the Hadley Centre model extensively, and many researchers into the impacts of climate change choose to use the Hadley Centre's output. Indeed, a current assessment of climate impacts in the USA is using output from the Hadley Centre.

16. An independent Science Review Group (SRG), composed of leading UK experts regularly reviews the work of the Hadley Centre. SRG meetings are held twice a year and explore one or two topical aspects of the climate prediction programme on each occasion. Separately, a major review, covering all aspects of the management, performance and scientific excellence of the Hadley Centre, was conducted 5 years after the Centre was established, and a 10-year review has just been commissioned. This will involve a wide-ranging review of the science of the Hadley Centre by a small panel of international experts. It will also include an assessment of its overall management and cost effectiveness, how well it delivers its products to the user community (policy makers, other scientists and the general public) and how it is placed to maintain its leading position in climate research.

17. The Hadley Centre models have been included in a number of independent international model intercomparison projects each of which focus on a different aspect of climate simulation. The two that have the most general coverage of present and future climate are AMIP (Atmospheric Model Intercomparison Project) and CMIP (Coupled Model Intercomparison Project). A similar project, PMIP (Palaeoclimate Model Intercomparison Project), is concerned with simulation of past climates, in particular the Mid-Holocene (6,000 years Before Present) and the last glacial maximum (21,000 year BP). Because climate conditions were very different at those times, and because relatively large amounts of palaeoclimate data exist for these periods, they provide a good test of climate models. All of these projects are hosted by the PCMDI (Program for Climate Model Diagnosis and Intercomparison), which is based at the Lawrence Livermore National Laboratory and funded by the US Department of Energy. The PCMDI assists in the projects with the provision of common validation datasets, model documentation and statistical analysis tools but the validation and comparison is conducted by individual sub-projects. There were 26 validation sub-projects in the first phase of AMIP, each of which addressed different areas and published their results in the peer-reviewed scientific literature. There are currently more than 100 articles in the literature from AMIP and CMIP. Some of the sub-projects have continued into the current phase of AMIP when more advanced models are being tested.

18. Despite the reluctance to define models as good or bad, the CMIP has recently concluded a comparison of 12 GCMs in which the Hadley Centre model was ranked in the top six for all indicators and ranked best overall in simulations of the current climate.

19. The Department also commissions its own independent validation of the Hadley Centre models. For nearly 10 years this has been undertaken by the Climatic Research Unit at the University of East Anglia. They have been awarded the contracts to undertake this work since they have unique expertise within the UK to undertake this task. Their work includes compiling approved datasets of climate observations, comparing different datasets including those from other sources, studying changes in observed climate, and comparing the Hadley Centre's and other climate models with the observations to assess the models' abilities to reproduce observed climate satisfactorily.

20. Key conclusions from the most recent contract with CRU included: "We have shown in earlier analyses the relative performance of Hadley Centre models in simulating the observed pattern of mean monthly precipitation for global land areas. These earlier analyses showed the generally superior performance of the Hadley Centre models over other modelling centres and also the improved performance between successive versions of the Hadley Centre model . . . Compared to other models, HadCM2 and HadCM3 are performing creditably." (Reference 3).

21. The ability of the models to simulate El Niño phenomena has also been examined by CRU. They concluded that "The observed levels of interannual temperature variability associated with ENSO events are best simulated by the HadCM2 model in comparison to other IPCC DDC (Data Distribution Centre) models" (although they went on to note that all of the models were deficient in some respect of their El Niño temperature response).

22. As well as comparing the most obvious outputs of the model (temperature, precipitation, El Niño) there is a move towards increasingly sophisticated validation. HadCM2 has been shown to reproduce the observed relationship between airflow and surface weather over the UK, ie not only are precipitation amounts correctly predicted, they are correct for the right reasons, increasing confidence in the model's use for national scenarios.

What is the nature of the UK's involvement with the Intergovernmental Panel on Climate Change? How important is the IPCC as a source of advice and guidance? How is IPCC advice delivered, assessed and used by Government?

23. This has been addressed in the opening to this Memorandum.

To what extent has Working Group 1 of the IPCC examined potential alternative explanations? To what extent have the results of such work been taken into account in the development of UK Government policy on climate change?

24. Working Group 1 of the IPCC has drawn on a wide range of scientific sources and has examined all natural factors potentially affecting climate, especially solar variability and natural, volcanic aerosol, which are the most important natural climate forcing mechanisms on the time scale of the current global warming. The IPCC concluded in the SAR (reference 4) that "The balance of evidence suggests a discernible human influence on global climate". However, they were not able at that stage to "quantify the human influence on climate . . . because the expected signal is still emerging from the noise of natural variability".

25. In the SAR the IPCC compared the observed pattern of climate change (using geographical, seasonal and vertical trends rather than a single global trend) with model simulations and concluded that "the probability is very low that these correspondences could occur by chance as a result of natural internal variability only. The vertical patterns of change are also inconsistent with those expected for solar and volcanic forcing." The TAR will assess the many new analyses of climate change attribution. For instance, the chapter headings of the TAR agreed in IPCC WGI plenary include "How well can natural factors explain observed climate change?" and "How well can anthropogenic forcing explain observed climate change?"

26. Another factor that has been suggested as giving the appearance of global warming is the biasing of temperature measurements due to changes in measurements methods and urbanisation. The IPCC devote considerable effort to correcting this effect but concluded in the SAR that the "estimate of warming since the late 19th century has not significantly changed" from the First Assessment Report, although the subject is still under review for the TAR. The SAR also notes that "Remote sensing techniques hold promise for the eventual world-wide estimate of urban temperature bias."

27. There are a number of other factors that affect climate, both man-made and natural, but are not directly considered in most climate models at present. Generally this is due to a lack of sufficient understanding of these factors and their effect on climate, as well as to the limitation of computational power. These factors are kept under review through the activities of contributing authors and through other international research programmes, which have close ties to the IPCC. In the SAR, the IPCC identified the most important of these as "the indirect effects of sulphate aerosol, the radiative effect of trace gases other than CO_2, and the forcings associated with large scale land use changes or the carbonaceous aerosols generated by biomass burning". (In fact the indirect effects of sulphate aerosol, and the radiative effect of gases other than CO_2, have since been included in the Hadley Centre model.) Each of these will be addressed in further detail in the TAR. Additional factors included for assessment in the TAR include forcings due to tropospheric ozone changes and the interactions between atmospheric chemistry and climate. Further attention will also be paid to the subject of solar forcing.

28. The SAR of the IPCC provided the Government with a clear indication that there was an increasingly urgent need to tackle climate change and it underpinned efforts to reach an agreement at Kyoto. It also provides the rationale for the UK to develop its domestic goal to reduce its emissions of CO_2 by 20 per cent, beyond its Kyoto commitments. The IPCC has also shaped the Government's appraisal of the long-term need to reduce emissions further and in due course to widen the scope to other nations of the need for emissions limitation and reduction targets. It is likely the TAR will provide an even clearer rationale to move beyond the Kyoto targets and will provide the scientific underpinning for negotiations for the second commitment period (2013–17) which has to begin before 2005.

Does the Government consider that, despite acknowledged limitations and uncertainities, climate change models are the most robust method for providing information on climate change? What, if any, other alternatives have been considered?

29. Yes, the Government does consider that global climate models, especially general circulation models (GCMs), are the most robust method for providing information on climate change. It is important that the method used to make future projections is capable of:

(a) simulating all the feedback mechanisms involved with climate, because these are where the main uncertainties lie and also because their interactions with each other need to be taken into account, and

(b) producing projections on a spatial resolution useful for understanding impacts and planning adaptation policies.

30. GCMs are the only tools capable of fulfilling these criteria. Other methods which have been considered and, indeed, are valuable in certain circumstances include simpler, less computationally-intensive models. For instance, these can be used to investigate the global average temperature changes which would result from particular emissions scenarios, and thus permit a wider range of policy options to be investigated, on a quicker time-scale, than would be the case using only GCMs. It should be noted, however, that the simpler models assume an understanding of the climate system, which can only really be provided through observations and GCMs. Simple models cannot of course provide regional predictions.

31. The DETR is currently funding the refinement of a well-known simple model, MAGICC, and its use to investigate the IPCC's new emission scenarios in time for their climate consequences to be reported in the IPCC TAR.

32. Other simple models are needed for some applications, such as investigating climate variablity on very long-time scales such as the study of ice age cycles.

33. Some have proposed that past climates, induced by varying solar forcing, can give an indication of the effects of climate change—so called "proxy climates". Indeed much can be learned about the behaviour of the climate system from studies of palaeo-data. However, such studies can only give imperfect insights into the response to greenhouse gas increases as they are related often to solar changes which, although of a comparable magnitude at the global scale, can affect the climate system in quite different ways at the regional level.

34. More generally it is important to assess observations of the climate. Recent studies on climate change detection and attribution rely upon estimates of natural climate variability (against which recent changes are measured). The short duration and very limited spatial coverage of the instrumental record has been supplemented with palaeodata from diverse sources, but the uncertainties associated with much of the palaeodata mean that in practice the best indication of natural variability is derived from the control run of a well-validated model. Whilst the Government does believe that this is a valid practice, it is keen to see the compilation of improved datasets. Examples of its activies in this area include:

- DETR is to be represented on the Steering Committee of the new NERC Thematic Programme PRESCIENT (Palaeoclimate Research and Earth System Modelling for Enhanced Climatic and Environmental Prediction);
- DETR and MoD are to co-fund (with an in-kind contribution from NERC) the UK contribution to the USA-initiated ARGO project, for improved global ocean monitoring of temperature, salinity and currents.
- The UK supports the GCOS initiative which aims to provide a global climate observing system which meets the needs of the UNFCCC process and underlying research on the climate system.

How adequate are existing global climate change models as a basis for policy development and implementation?

35. To answer this we need to consider the key policy issues. Firstly policy makers wanted to know (a) whether climate change was already happening and (b) how serious a problem it is for the world as a whole and for the UK. Secondly, if it is decided it is a problem then we need to assess the response of the climate system to different mitigation policies and also to consider adaption requirements.

36. Full climate models (GCMs) enable us to explore all these issues by assessing historic changes and the projected changes in climate given future greenhouse gas emission scenarios. They are based on physical principles so they do not depend on some calibration period. This is important when we are going into uncharted territory. Climate models are spatially resolved so can, in broad terms, identify specific regions that could be particularly sensitive to climate change. By being physically based it is possible also to explore the sensitivity of projections to uncertainties in our understanding and quantification of physical processes. It is also possible to explore non-linear changes, such as rapid changes to the ocean circulation—and the Hadley Centre and other modelling centres have done this. They can also be used to investigate potential feedbacks such as the effect of warming on cloudiness or effects on the carbon cycle.

37. With regard to the first issues, question (a) was a key issue in the first half of the last decade. The Hadley Centre was the first to use a full ocean-atmosphere GCM to assess the match between the historic temperature record and the historic increase in greenhouse gases and aerosols. Their initial results showed clearly that the temperature rise and the key forcing mechanisms were consistent. This work contributed significantly to a key conclusion of the SAR that "the balance of evidence suggests that there is a discernible human influence on global climate." This work has been refined to show even more clearly that the recent rise in temperature cannot be explained without taking into account the rise in greenhoue gas concentrations.

38. On question (b) above, a variety of types of climate models can be used to assess future climate changes but the most comprehensive tool is the GCM as noted above. In fact only GCMs can provide the spatial variation in climate predictions which are needed to assess the potential impacts on human society and the environment. Since these are local, GCMs can provide enough spatial detail to investigate impacts and adaptation issues. GCMs are thus also suitable for addressing the impact of different mitigation policies and

the need to adapt. Recent work at the Hadley Centre with impact modellers has enabled us to assess more quantitatively the impacts of climate change and these show that impacts become increasingly serious under a middle of the road business as usual scenario towards the middle of the next century with the potential for significant loss of tropical forest and the numbers of people at risk from hunger and dislocation due to sea level rise.

39. On the second main issue, increasingly GCMs will be used to assess adaptation needs. These require models with increased spatial resolution, and the Hadley Centre has developed regional models, which provide this, and increasingly sophisticated impact models.

40. State of the art models, such as those used at the Hadley Centre, are now very sophisticated and powerful tools. Even so they cannot be used without interpretation. Projections of future climate change depend on our assumptions about emissions scenarios, as well as the sophistication of the models. However, even the best models need to be tested and their response understood in detail. This is particularly true at the local and regional level when assessing impacts and adaptation. Indeed, it is essential to consider ensembles of model runs (using the same forcing factors—greenhouse gas emissions for example but slightly different initial conditions) and where possible to compare results from different models. This is a very active area of research and requires careful consideration of uncertainties. Nevertheless, we have no other tool that could adequately predict the effects of climate change at the regional scale.

What mechanisms exist to ensure co-ordination of research effort and policy development across Government departments in relation to climate change?

41. Climate change policy is co-ordinated through an inter-departmental committee (the Inter-Departmental Liaison Group) and, in the widest sense, research is co-ordinated through the Inter-Agency Committee on Global Environmental Change (IACGEC).

42. In addition the Department's research programme plans are reviewed by research managers and co-ordinators from other government departments and the research councils. Departmental plans are usually circulated for comment and Research Council proposals are usually sent to DETR for comment. Departmental science advisors have been invited from time to time onto the steering committees of NERC thematic programmes and have served on the various NERC Boards. The DETR also funds the UK Climate Impacts Programme, with the aim of drawing stakeholders of all kinds, including other Government Departments, into the debate.

43. The DETR also provides the focal point for IPCC and seeks comments widely across Government on IPCC reports and keeps them informed of developments in the IPCC.

REFERENCES

1. Bolin, Bert *et al*, 1986: *"The Greenhouse Effect, Climatic Change and Ecosystems"*, International Council of Scientific Unions.

2. Tett, Simon F B *et al*, 1999 Nature 399, 569–572, *"Causes of twentieth-century temperature change near the Earth's surface"*.

3. M Hulme, Final Report to DETR for contract EPG 1/1/48, June 1997 to March 1999.

4. Houghton, J T *et al*, *"Climate Change 1995: The Science of Climate Change"*, Cambridge University Press.

APPENDIX 1

LIST OF ACRONYMS

ARGO	Array for Real-time Geostrophic Oceanography, an array of instrumented buoys for measurement of temperature and salinity throughout the ocean.
CRU	Climatic Research Unit.
ECI	Environmental Change Institute.
GCM	General Circulation Model.
GCOS	Global Climate Observing System.
IPCC	Intergovernmental Panel on Climate Change.
ITE	Institute of Terrestrial Ecology.
MAGICC	A simple climate change model for rapid investigation of emission scenarios.
NERC	Natural Environment Research Council.
SAR	Second Assessment Report (of the IPCC).
TAR	Third Assessment Report (of the IPCC).

UEA	University of East Anglia.
UNEP	United Nations Environment Programme.
UNFCCC	United Nations Framework Convention on Climate Change.
WGI	Working Group 1 (of the IPCC, Science of Climate Change).
WMO	World Meteorological Organisation.

8 March 2000

Examination of Witnesses

The Rt Hon Michael Meacher, a Member of the House, Minister for the Environment, Dr David Fisk, Chief Scientist, and Mr David Warrilow, Head of Science Policy, Global Atmosphere Division, Department of the Environment, Transport and the Regions were examined.

Chairman

116. Minister, welcome this afternoon to the Science and Technology Select Committee and welcome too to the colleagues you have with you. In just a moment, perhaps, I will invite you to introduce them but can I just give you the setting in which we are going to take evidence this afternoon? We embarked, in this Committee, some time ago on a major inquiry into the scientific advisory system to government. We decided that we would publish the chapters of each section as and when we had completed them and we had conclusions. Our first one was on genetically modified foods, as you may recall. Our second one was on mobile telephones. Our third one was on diabetes and the driving licence. Our fourth one is scientific advice on climate change. I hope that you have been briefed on the fact that we are not going to debate the whole issue of whether there is or whether there is not climate change. We are assuming there is climate change; we are assuming there is global warming; and we are assuming that it has come about by increased CO_2 and other climate change gases. Having those givens, we can then look at what advice government is receiving, the quality of it and how it is reacting to it. We do not wish to go into a great, lengthy debate about whether there is or is not, because we will never get through it. This is our fourth chapter and our final chapter in this scientific advisory system inquiry that we are very nearly finishing at the moment. That said, Minister, having welcomed you, would you kindly introduce your colleagues to us?

(*Mr Meacher*) Thank you very much, Chairman. It is a great pleasure, if rather a daunting one, to appear before a Committee all of whose members are prefixed by "doctor". I am not one myself. On my left is David Warrilow, who is head of science policy of the Global Atmosphere Division of the Department. On my right is David Fisk, who is chief scientist and responsible for central strategy.

117. And is a doctor?

(*Mr Meacher*) Yes. I am daunted by that too.

118. You submitted a memorandum to us last March. I wonder if you would like to update us on developments of climate change since that memorandum was sent to us?

(*Mr Meacher*) I am sure my colleagues will know more about this than me but one document which I thought I would bring with me—I had not expected it to be so immediately relevant—is this which is *Climate Change, an Update of Recent Research* from the Hadley Centre, dated November 2000. This had a remarkable effect. I just returned a few weeks ago from a bruising week in The Hague discussing this matter and again in the last couple of days in teleconferencing with the United States and others on the same subject in Brussels. One of the issues which came up at The Hague was the evidence presented by the Hadley Centre there on the predictions of accelerated climate change resulting from interactions with the carbon cycle, the fact that the gradually accelerating pace of climate change affects the operation of carbon sinks, because it accelerates the speed at which forests die back, and that has an immediate impact on the degree of sequestration in absorbing carbon and therefore being permitted as one of the means by which countries can reach their targets. Perhaps I could read this paragraph, since it had quite an impact at the conference: "However, the results do clearly show that the beneficial effect on climate of the additional carbon sinks created by afforestation and reforestation"—which many countries have been relying on quite extensively—"may be at least partially offset by changes in the surface reflectivity as dark trees replace land cover that was lighter in colour. Consequently, in many areas, the climate benefits of planting extra trees will not be as great as their carbon sink potential suggests." Since that was probably the single biggest issue of contention between the European Union and the umbrella group, particularly the United States, that is a glowing testimony to the impact of the Hadley Centre as a prime contractor of research in impacting on the policy process. It had a major impact at The Hague.

Dr Williams

119. This is a new argument that has only appeared in the last few months or so. It is a very challenging argument in the sense that everybody thought that afforestation or cutting down tropical rain forests were intimately linked, part of the problem and part of the solution. This idea of surface reflectivity is a physicist's idea, not a biologist's idea and I think it gets at the root of what may be a problem in the Hadley Centre in that is that it is packed with mathematicians and physicists and does not really have the biologists. I am very sceptical of this. Is there

[Dr Williams *Cont*]

not potentially a big problem in the Hadley Centre in that it is physical science based and does not have the biological input?

(*Mr Meacher*) My understanding is that it is increasingly taking account of biological processes.

(*Mr Warrilow*) I would confirm that the Hadley Centre is taking account more of biological process, but it is doing this not by working in house so much on it but by working with others who have expertise in this area. For example, the work which is quoted in here and was published recently in *Nature* on the feedback effects of the carbon cycle in climate change was work which was carried out in conjunction with scientists from the NERC Centre for Ecology and Hydrology in Edinburgh and Wallingford, which indeed include people with a biological background. We also have links with biologists who work at the Institute of Oceanographic Scientists in Southampton, who are looking at the carbon cycle in the ocean.

Chairman

120. Minister, the United Kingdom Government appears to be one of the first to accept that there has been a major contribution to climate change brought about by man's activity. Do you think that was because there was scientific advice on it? Do you think it was a political decision that was thought to be appropriate for political PR reasons, or do you think it was a precautionary principle? For what reason do you think we have been so in the vanguard of climate change action?

(*Mr Meacher*) The quality of performance of the Meteorological Office and in particular of the Hadley Centre is highly relevant here, but the persuasive impact on opinion worldwide does come from IPCC, the Intergovernmental Panel on Climate Change, which provides the overall assessment of the science and of the impacts and socio-economic responses to climate change. The Hadley Centre is a prime contractor of research. It does research which is relevant to IPCC, but IPCC of course is an international body; it is supported by the work of several thousand scientists; it is peer reviewed both in the journals and in the whole process. I would say that that has been the major driver scientifically for changing opinion, plus of course in the last three to five years actual experience on the ground which has persuaded the general public that something different and more serious is happening. The reason I think why we have been able to take the lead in that process—and after all Sir John Houghton was the chair of working group one, which is the most important of the three committees of IPCC—is because of the work done in this country, particularly by the Hadley Centre which I would have said was a world leader, if not the world leader.

121. One would hope that science well done and properly presented could survive the change of government from one political party to another, but bearing in mind that many of the decisions that were taken on climate change were taken by the previous administration, have you found any need to have second thoughts about any serious aspects of what was done by the previous administration? This is not a political question; this is a science question.

(*Mr Meacher*) I would never think that of you and I think that is a perfectly fair question. I am not aware of any way in which we have changed our direction of policy. There have been institutional changes but they might well have occurred anyway under the last administration, not connected with the ideological flavour of the Government. I entirely agree with you that I think the science base is very secure; I think it is respected by all the parties that form government and I do not think that any of those parties would seriously interfere with the thrust of that work. Certainly we would not.

Dr Gibson

122. When you want advice on some climate change issue, do you always go to the Hadley Centre first or are there other centres of excellence in particular areas that you would go to first? How does it actually work in practice when an issue comes up where you have to have a position?

(*Mr Meacher*) I repeat that the main source of information is IPCC. The work of that body is based on a number of models. They are increasingly being refined. If you say how do I get my advice, I get it from the Department. That is based on the contracted research, particularly at the Hadley Centre, but also on external research and also on international peer assessment, for example through the IPCC process again. In addition, I do have the privilege of meeting scientists, albeit for too short a time. I opened the Tyndall Centre in Norwich on 9 November and I did have some significant discussions with scientists on that occasion. I only met them for an hour or two, which is a very short period of time, but those are the sources of information.

123. What is the Tyndall Centre going to do that the Hadley Centre is not? Why should we have another centre like that?

(*Mr Meacher*) It is an independent source of data. It brings together climate change scientists, engineers, economists, social scientists from nine higher education research institutions. The aim is to develop radical new responses to climate change and to try and inform the policy process better. In addition to IPCC, in addition to the Hadley Centre, it is a way of brigading research on climate change in an integrated way of relevance to government and industry which is very helpful. However good the Hadley Centre is—and I think it is extremely good—to rely exclusively on one body would be unwise in an area which is so multifaceted and where it is so difficult to achieve an absolutely comprehensive picture. There is also the point that we are not just talking about understanding of facts and causes; it is not just about cutting greenhouse gas emissions. It is also about adaptation and that is a much wider issue. It is not just about science; it is about socio-economic impacts and involving public and local authorities.

124. How is the Tyndall Centre being funded? What degree of permanency does it have?

(*Mr Meacher*) The Natural Environment Research Council in the last spending review, SR2000, received an extra £39 million which funded investment in e-science applications in the climate

[**Dr Gibson** *Cont*]
change field. It also paid for, I understand, research into rapid climate change in north west Europe, which we are doing alongside Norway. That is about changes in the North Atlantic Ocean, but thirdly it paid for the Tyndall Centre. I am being told it is £10 million over five years, but the source of it is out of this last spending review.

125. How is the Hadley Centre reviewed? I believe there is a ten year cycle. Where are we in that cycle now?

(*Mr Meacher*) It is being reviewed at the present time because all major public institutions where significant sums of public money are involved over a period of years are subject to a rigorous review. The cycle is five years.

126. How independent is the Hadley Centre of government? It sounds as if you are in love with each other.

(*Mr Meacher*) Only because of the quality of its advice and because of its generally superior performance over other models and its improved performance with further versions of the Hadley model. All of that is for factual comparison with other models. It is certainly not a private or personal view. To that extent, I think we are dependent on it but I repeat it is all peer reviewed. More and more material is written into the models on solar variability, volcanic aerosols, the forcings due to major changes in land use, carbonaceous aerosols. All of these are increasingly being incorporated into the model and indeed I believe increasing comparisons with palaeoclimate. In preparation for this, I was pleased to understand that there is quite a lot of data about the climate in the mid-holocene, 9,000 years ago, and at the last major glacial maximum about 21,000 years ago. All of that is being incorporated increasingly to refine the quality of the model and I think it is being done better here than anywhere in the world. It is not perfect. Until we get an absolute, total match between looking at what the theory predicts on the basis of data should have been the pattern of global temperatures over the last hundred years and it totally matches what we actually experience, we will not have a completely perfect model, but it is getting close to it. The addition of sulphate aerosols has increased its effectiveness considerably.

127. There are some people who question peer review now and it is maybe time for a good old look at it again, at how effective it is, because science has changed very much from the earlier days when peer review was first evolved. I want to ask you about dissidents in this field. It is a field where there is a lot of argument. Where do you pick up the dissidents and the people who do not agree with the Hadley Centre or the Tyndall Centre?

(*Mr Meacher*) I repeat again that we rely primarily on the IPCC which uses a number of models, not one. To that extent, you can say that we use a number of different models. The United Kingdom climate impact change scenarios were largely modelled on the Hadley change model, although with some adjustments, and we have commissioned our own independent valuation of the Hadley Centre through the Climatic Research Unit at the University of East Anglia. Again, we have been careful not to put all our eggs in one basket but to look for independent valuations, where appropriate. I have to say I think the Hadley Centre comes out of all of this extremely well.

Dr Williams

128. Our main inquiry, of which this is part four, is on scientific advice to government. Generally, these advisory committees are independent of government, staffed with academic experts and so on. In this area of climate change, the role of the Hadley Centre and its closeness to government is a very different model compared to some of the other committees we have been looking at. Do you accept that the Government depends very strongly, even overwhelmingly, on the Hadley Centre and that there will be dangers if other advisory committees work so much hand in hand with government?

(*Mr Meacher*) I do not feel that we are unduly dependent on the Hadley Centre or that there is some close nexus which you seem to be suggesting into government policy. There are many other relevant bodies which are involved here.

(*Dr Fisk*) My enthusiasm is really to speak on behalf of the IPCC. The IPCC is pretty well the formal equivalent of the advisory committees that you are referring to. It provides summary advice across the whole field, using probably what is a gold plated process compared with the normal way of assembling scientific advice in the United Kingdom. The Hadley Centre is a research contractor that helps us on interim positions. But there is no position that the Government has taken in any major White Paper which is not actually to be found in the IPCC process, which is, as colleagues have said, one of the most inclusive international peer review systems in an open, transparent process that you can find anywhere. That would be our model. If the Committee is looking for models of advisory process, it would be the IPCC. The Hadley Centre is part of that process. If the IPCC were to conclude that the Hadley Centre model was worthy but not excellent, then we would be taking the IPCC advice.

129. The danger of what I say is an incestuous relationship with government in this area of advice would be compensated for by the fact that it draws from the international advice?

(*Mr Meacher*) Can I ask why you feel that there is an incestuous relationship? The very fact that it is all peer reviewed in the journals and indeed through the peer review process of IPCC means it is not as though they have an inside track into government policy. I am not sure why you do not regard them as independent in a proper, scientific manner.

Dr Williams: If there were other advisory committees on, let us say, GM foods, BSE, nuclear power or in more controversial areas—fortunately here there is a wide consensus that goes with the advice from the IPCC—but if this was the model for other advisory committees being too close to government that would have dangers of excluding dissidents as my colleague from Norwich pointed out earlier, or just drawing the advice from something that is government-funded and government-responsive, you may miss out.

Chairman

130. Are the peer reviewers also government-funded?

(*Mr Meacher*) Not as far as I know. All of this material is published and all of it can be reworked, examined and checked by any others. That material will itself be published. This is the normal scientific process. To that extent, it does seem that the Hadley Centre is free from the claim of an over-cosy relationship with government. I do not think it could develop, given the openness and transparency of the whole process.

Dr Williams

131. If the Hadley Centre is well set up and well thought out in its staffing and the emphasis that it gives to different fields, that would be fine, but the accusation has been made that it is too much concerned with climate modelling. There are very good mathematicians and physicists, very good models of world class standard, but maybe it is missing out on biological inputs. Could you give some idea as to the staffing of the Hadley Centre in terms of these scientific disciplines? What proportion of its employees, of its scientists, are from the biological, ecological or environmental sciences as opposed to maths, physics and chemistry?

(*Mr Meacher*) I will ask my colleagues to answer that because I cannot, but it is the case that there is a growing body of work which has looked at the carbon cycle on oceans and land and, in particular, the Hadley Centre has recently published a paper about the interaction of the land biosphere and climate. They have published material which shows—and I was partly quoting it—the large feedback that exists between climate change and CO_2 emissions from the biosphere. I do not think it is over-dominated by physicists and mathematicians. David, what proportion are there in the biological disciplines?

Chairman

132. Mr Warrilow, you have touched on it earlier. If you have difficulty giving a precise answer, we would be very pleased to receive a letter from you but if you could give us a ball park answer that would be very helpful.

(*Mr Warrilow*) I cannot give you a precise answer at the moment. It is not admittedly the traditional discipline of the Meteorological Office, of which the Hadley Centre is a part. There is inevitably a preponderance of mathematicians and physicists. That is correct, but the aim is to compensate for that by working with other bodies who have the right expertise outside. We have in the programme joint work with for instance the Institute of Terrestrial Ecology, which is part of the NERC Centre for Ecology and Hydrology and other organisations as well. That is the way we compensate for that. There have been some people brought into the Hadley Centre who have a background in the biological sciences and in chemistry as well, because that is another important aspect of climate change, but it is certainly not an attempt to make the Hadley Centre do everything that can be possibly done in the scientific disciplines because they are so wide and it is strategically better to work with other bodies.

133. You will write to us?

(*Mr Warrilow*) We will[1].

134. If you could, when you write, not only tell us what the situation is but tell us what your target would be to change the situation in, say, two years' time, that would be helpful.

(*Dr Fisk*) The Department's view is that one of the strengths of the Department's programme on climate change is that we have not focused all our funding on the Hadley Centre. The Hadley Centre is probably a world class resource of the underlying climate change predictions which are used by the climate impact research community, but we have tried to avoid the Hadley Centre being too closely involved in climate impact because it is not a core skill inside the Hadley Centre. The programme over the years developed by David Warrilow and his colleagues has been to have a fast track process by which the Hadley Centre predictions are put out into a very wide network in the United Kingdom and elsewhere. You will notice that when the new Hadley Centre model predictions come out, they are associated with an assessment of what their impacts are, not by Hadley Centre staff, but by key operational people within the wider NERC research community. That has never been done anywhere else before and it is one of the reasons why the Hadley Centre predictions are widely referred to in American research literature. They are much more useful to a much wider community. I think our own feeling is probably that of the Committee's, that if we had simply made the Hadley Centre the centre of everything it would become unstable and not open to the broader challenge of the scientific community.

Dr Williams

135. My line of questioning is in order to draw out this criticism made of the British position in The Hague summit that the role of carbon sinks is insufficiently recognised. Is there a danger here that we are underestimating or misunderstanding or government is not being sufficiently informed of the role of carbon sinks?

(*Mr Meacher*) There was a great deal of discussion about carbon sinks at The Hague and again this last weekend in Brussels. The problem is that while sequestration undoubtedly does occur through afforestation the degree to which you can attribute percentages against targets for countries due to human management of forests over and above natural phenomena is very uncertain. There are also the key problems of scale, uncertainty and risks involved with carbon sinks. It was our calculation that, whilst Kyoto at a five per cent reduction would imply something like a reduction of 250 million tonnes of carbon in a year, if we were to allow sinks both in northern countries, in annex one countries, and in the CDM and developing countries, that could increase the permitted generation of CO_2 by something like 1.8 billion tonnes. To that extent, the

---

[1] See p .

[**Dr Williams** *Cont*]

whole question of scale is extremely worrying. That is why we wanted a very, very cautious attitude to this until the science can reliably show the relationship between afforestation or reforestation and genuine absorption of carbon. There is of course the whole question of high level burning of biomass which we saw in Indonesia and Brazil a year or two ago, where again more CO_2 was discharged into the atmosphere than probably the total savings of CO_2 by action taken by all the European countries. That is our concern, not to deny it as a scientific process, but to say that it is very uncertain as to what those relationships are. Secondly, the fact that accelerating climate change may reduce the effectiveness of carbon sinks quicker than we would like. Thirdly, destruction of rain forests by fire is a double whammy in the opposite direction. You lose sequestration of carbons and it is all generated into the atmosphere.

Dr Jones

136. Was the deal brokered by the Deputy Prime Minister acceptable?

(*Mr Meacher*) Since I was heavily involved, I would say yes.

Dr Turner

137. Could you explain to us the workings of the IPCC and its relationship to government policy forming in the United Kingdom and tell us why you evidently think it to be an effective body?

(*Mr Meacher*) These reports which are authored reports by scientists from around the world—I think 3,000 to 5,000 scientists are involved; it is on a very substantial scale and they represent some of the most distinguished scientists in terms of track record that you can find anywhere—are the best evidence available worldwide. We therefore take them extremely seriously. Our own Hadley Centre and other bodies flow into that but it is the sheer range and quality of the work. If you are concerned with international acceptance, which is absolutely integral here, if one is looking for openness, if one is looking for comprehensiveness, I think IPCC is a very good process. It is very cumbersome and time consuming, but where there is a degree of controversy, where it is a very complicated, multifaceted subject, as it is here, and where there is a need for nations to work together, I think IPCC is just the right process.

138. Do you think there is a risk associated with the consensus approach in that it may dilute the advice and underestimate problems or results from global warming in the interests of suppressing opinions to arrive at consensus?

(*Mr Meacher*) I think this is an area where dissidence, as far as I know, is certainly not suppressed, where it has plenty of opportunity for expression, where the media, somewhat perversely, are probably giving far more inflation to the views of the dissidents because it creates a story, because it is cocking a snook at the general conventional wisdom than those who are refining what is I think an extremely well founded and increasingly reinforced core theory. I do not believe that dissidents' different views are concealed. In fact, any serious, new evidence would not be suppressed; it would become a major issue for scientific examination and investigation across the world until it either could be explained or, if it withstood the test, the theory needed to be changed in some way.

139. How are national scientists selected to participate in IPCC? Is it by the IPCC itself or does government nominate them?

(*Mr Warrilow*) We are invited to nominate scientists. We went to a large number of people, asking them if they would like to be part of the process. There were something like 120 scientists who we nominated in the United Kingdom. The roles which they actually play once they have been nominated are up to the IPCC to choose. It is possible for people to nominate themselves as well, so they do not have to go through government, although it is important, usually because the IPCC is an inter-governmental process. That is the first point of contact the IPCC has with countries. Also, international organisations are invited to nominate experts, so there is quite a wide range of input from across the world.

140. We have been told that there is quite a difference between the full IPCC reports which give the full range of scientific views that have been taken into account and policy makers' summaries which contain the agreed consensus. In your own policy making, do you draw on the full report or depend primarily on the summaries?

(*Mr Meacher*) The full reports, which are authored reports, are written by a range of independent scientists from across the world. The summaries, which are written for policy makers, are agreed as part of the inter-governmental process, although of course they are drawn exclusively from the underlying report. I have a copy of the second report of the IPCC at home. If you are asking about my personal understanding of this report, I have dipped into it. It is a daunting volume, clearly a very high quality of work, extremely detailed and what I have read—which I must say is largely confined to summaries, simply because of the problem of time—is extremely persuasive. I would always prefer to go for the actual report rather than a summary which had been prepared for me, not necessarily because I think it has been tampered with or filtered, but just that it is best to use the basic material, even if on the summary form at the end of chapters one then relies on summaries.

141. Do you think IPCC is a particularly good model for scientific advice to government? Do you think it is a sufficiently good model to promote it for use in other controversial areas like GM organisms or ocean pollution?

(*Mr Meacher*) It may be. Indeed, we are coming to see, over genetically modified organisms, that there is quite a lot of pressure for building a world process for the assessment of the data, partly because that is the best way of ensuring that all relevant data is absorbed into, so far as possible, a single, composite theory; but also of course to encourage confidence amongst the public, because the frenzied attack which has been made on genetic modification causes many members of the public to regard it with something close to panic. Without saying whether genetic

[Dr Turner *Cont*]
modification is a good or a bad thing, it could certainly be looked at in a considerably more balanced, thoughtful, comprehensive and detailed way than we have at the present time. It may be IPCC is one way of approaching that.

142. Would you be prepared to promote the model internationally?
(*Mr Meacher*) I would certainly be very happy to. We keep saying in the United Kingdom that we have a tough regulatory framework. I believe that is true although incidents like the Advanta incident show always that there are problems even when you try to have a comprehensive framework and there are still incidents which cause problems. I think there is a need for the public to have confidence that it is not just the United Kingdom but internationally and that all the relevant data is being assembled and that a very large number of reputable scientists are looking at this. As has been said by Dr Williams, there is much more controversy about the issue of GM than there is about climate change. Scientific opinion is overwhelmingly in favour of the fact that anthropogenic global warming is occurring. There is a real division between scientists on genetic modification, let alone the policy makers. It is the openness of it; it is the fact that it is an appropriate model when you are dealing with issues of great controversy and where there is a need to try and get agreement across countries, because it is not only what we believe in the EU; it is what they believe in the north American continent, and to try and reconcile that data and not pave the way for a trade war.

Chairman

143. The IPCC is presumably quite an expensive organisation. Do you think it gives value for money? I suppose you are going to say, "Yes, it does", but does it give enough value for money for it to be considered to be a model for GM foods or oceanography, as Dr Turner is asking?
(*Mr Meacher*) I will ask my colleagues to give you the figures, which I cannot, as to the United Kingdom's cost but since I take the view that accelerating climate change is arguably the greatest threat to the human race that we have ever faced, if one thinks about whether we have a future at all for the next 300 to 500 years, almost any cost would be justified, but I would much prefer to give the actual figures if we have them.
(*Mr Warrilow*) I do not think we have ever formally tried to assess the total cost of the IPCC process in the global sense. The United Kingdom contributes some £140,000 a year to the overall running, which is to help developing countries participate. We also fund the technical support unit, working group one, of the IPCC, which runs at around £450,000 a year. That is the technical support unit that meets the production of the working group one report which is chaired by Sir John Houghton. We also support a number of the lead authors to attend meetings. We pay their travel and subsistence.

144. You are not talking about £1 million in total?
(*Mr Warrilow*) No.

145. When you started off with 140, I thought you had made a mistake when thousands came out; I thought you were going to say millions. It is very little.
(*Mr Warrilow*) What we have to realise is that a lot of scientists provide their own time or at least their institutes provide their time. They are not paid for. If we factor that in, the cost will rise considerably.

146. Without the IPCC, those scientists would probably still be doing that work anyway so if you abolish it that will not stop. I think you have answered the point in the spirit in which I meant it. It is funded by international bodies, presumably. Do the UN fund it?
(*Mr Warrilow*) The majority of the money comes from developed countries. The overall annual budget is something like ten million Swiss francs.
(*Mr Meacher*) It is absolutely minuscule. Compared to public accounts in this country of about £330 billion, a million is chicken feed.

Dr Iddon

147. Climate change is clearly a very uncertain science or it certainly has been in the past. You mentioned today the various models that are being explored and constantly changing to take in new factors. How do you cope with scientific uncertainty of that kind when formulating your policies?
(*Mr Meacher*) This is a very difficult issue. It is better coped with by the scientific community. They are able to communicate levels of certainty, but I think it is much more difficult for the public. They want to be told the facts. They want to be told what the situation is and therefore what they have to do. They want government to get on with doing it. They find it extremely difficult to cope with the fact that this is a multifaceted theory. There is the coronal cycle of sunspots and vulcanism. The Mount Pinotubo explosion in 1991, if I remember, had a major impact on the climate. Indeed, some people think the long term ice age cycles are still reflected and having some impact on current cycles. The public find it very difficult to cope with. The IPCC has drawn up some guidelines which try to communicate degrees of uncertainty and perhaps that is the best starting point for trying to have some common standard of uncertainty. It is one that people are very resistant to, but it is one which is necessary and we have to try and communicate it better.

148. It has been suggested that policy makers do not like uncertainty and wherever the information is coming from they put back pressure on to get black and white answers. Do you feel that is true?
(*Mr Meacher*) I was trying to pass the blame onto the public but you are quite right that policy makers equally like certainty. Particularly when you have to deal with the Treasury, as we do every day of our lives, it is much better to speak in terms of certainties than in terms of weighted probabilities which is not the way by which the Treasury tends to allocate money for particular purposes. It is difficult. I cannot deny it, but we have to try and be mature and realise that a lot of this evidence has a margin of uncertainty

[Dr Iddon *Cont*]

which is unavoidable, although I think that is steadily reducing and this is almost universally accepted.

149. You have hinted at the answer to the next question but I will pose it anyhow. You must be inundated with independent scientific advice on climate change as well as other things. You are obviously a busy minister. Do you rely greatly on summaries of that information or do you try to get as much of the direct evidence as possible? In other words, how much of the scientific advice that you are seeing as a minister has been strongly filtered by your civil servants?

(*Mr Meacher*) We need to ask them that, because all I see is the filtered result. I do get letters from "mad scientists" or people who have a bee in their bonnet or have a particular view that they are extremely keen, preferably to see the minister or, if need be, write. Officials always very generously suggest that the draft reply should say that officials will see this person and that will be the end of it. I try to make an assessment. I read these as best I can and there have been odd examples where I have been keen to meet people and I have done so. David, how much do you filter what reaches me?

(*Mr Warrilow*) We have to be concise, clearly. We try and provide you with frequent advice. Particularly as new results come to the fore, we inform you of them. Quite often, we would attach the scientific paper that our summary would draw on. I do not know whether we always do that but we try and do it if necessary, particularly if it is work which is published as a result of departmental expenditure.

Chairman

150. I think it is very much a "when did you stop filtering your minister" type question.

(*Mr Meacher*) I do believe that this is an area where the quality and range of advice which I am getting is extremely high. I do not have suspicions about what I am not being told as I do occasionally in other areas.

Dr Williams

151. How does the precautionary principle apply in this area of policy?

(*Mr Meacher*) The precautionary principle which says that where the evidence is less than certain but of a sufficient degree of persuasiveness as to justify and indeed strongly pressure the need for some action to be taken, just in case it turns out that the suspected consequences are true—that is not a very good expression of the precautionary principle but I think the thrust of it is right. The precautionary principle I would say here is very powerful. The Kyoto conference of the world nations, and in particular the annex one 35 countries who are mainly responsible in the developed world, was accepting targets under the Kyoto protocol based on the precautionary principle. In 1997 or even now, the degree of absolute certainty or the degree of other factors which may be influencing the long term variability of the climate is still not totally known, but we are taking action, or trying to take action. Most of us accept the view of the Royal Commission on Environmental Pollution in its recent report—and it has been said in other countries as well—that we should be aiming not at a five per cent reduction but a 60 or 70 per cent reduction because the object of the exercise is to stabilise the level of greenhouse gases in the atmosphere, which were about 280 parts per million in the pre-industrial age and are now about 370, and are probably irrevocably fixed to reach 450/500, almost whatever we do, and could certainly go higher if we do not take the action. There are very powerful grounds for taking action now and I would have said the precautionary principle operates more in this area than almost any other I can think of.

152. I am pleased that you quoted that Royal Commission figure. Do you feel a sense of horror when you see 50, 60 and 70 per cent reductions will be necessary in a few decades?

(*Mr Meacher*) If the scientists say—and as a mere politician I have to accept that they are right—that if we are going to stabilise, let alone begin to reverse the levels of concentration of greenhouse gases in the atmosphere we have to achieve those sorts of levels and indeed, if you are tempting me to go further, I will. We have a global, single atmosphere for the whole world and if the developing countries are going to achieve their levels of industrialisation and better living standards that they want to imitate ours, consistent with not going beyond what most people regard as broadly safe levels which might be 550 parts per million, we are going to have to accept even bigger reductions in the developed world and I have seen figures suggesting 90 per cent reductions. 60, 70 or 90 per cent reductions are absolutely mind-blowing in terms of the real politik today. I have asked my Department to produce simply an outline of what might be involved with a reduction of 60 per cent in CO_2 in this or any other industrialised country. I have not seen that yet, but I suspect that it will be sufficiently worrisome that the Department will be extremely unwilling to publish it, but we shall see.

Dr Jones

153. Have you not just argued that the precautionary principle does not apply? You are saying that the Royal Commission was predicting that we needed to reduce emissions by 60 per cent and yet we are nowhere near that. When you were referring to the precautionary principle, were you talking about unilateral actions by this Government or international actions?

(*Mr Meacher*) I am certainly talking about international action. It is next to pointless for a country the size of the United Kingdom, with one and a half per cent of the world population, to seek to—

154. Exactly. So where is the evidence that the precautionary principle applies?

(*Mr Meacher*) The fact that, *mirabile dictu*, the nations of the world did agree in December 1997 on a set of targets. I agree on the difficulties we have had at the Hague at COP6 in trying to ensure that they signed up to specific targets and detailed implementation. I like to think they are probably the kind of problems that you would expect in anybody

[Dr Jones *Cont*]

who finally has to face the truth and to confront the dramatic changes in behaviour which are going to be required across society and across the economy. I still believe that the level of impact of the frequency and increasing severity of those climate change impacts which we have seen in the last three to five years will persuade all countries, including the United States, that it does have in the next few years to sign up, to ratify and carry through a programme of changes on a scale which even today can scarcely be contemplated. I think it is absolutely necessary, and no country in the world can escape.

155. You are hoping the precautionary principle might apply soon. Can I move on to the questions I am supposed to be asking? It has been suggested that we do not have a coherent national research programme on climate change. How would you respond to this view and are there areas in which you would like to see more research, and what are they?

(*Mr Meacher*) I would have said that we have had one of the most effective, if not the most effective research programme on climate change anywhere in the world, which we have already talked about. If you are looking at how far it is coherent within the United Kingdom context I would have said, again, more than in any other areas I can think of, there is inter-departmental liaison. There are working level contacts with the research community which I think are very close. If you look at comparisons with other countries they do have a top-down programme which is imposed and perhaps is more centralised and perhaps you might say more coherent, but I would argue that the strength of the United Kingdom programme is the relative independence of thought between the different funders of research, as I have already indicated, in what we have talked about in the various models of the different institutions. It is also true that there is a division between the majority of the strategic science which is undertaken by the Natural Environment Research Council and all the policy-driven policy-relevant questions which are dealt with by DETR. In my view, we get quite a good mix of different bodies with different responsibilities but, at the same time, a coherence in the process which causes a central body of policy-making to be possible and, whilst being challengeable, nevertheless to be accepted.

156. Your memorandum refers to the Inter-Agency Committee on Global Environmental Change having a role in co-ordinating United Kingdom research. We understand this body has recently been wound up. Why has it been wound up and has it been replaced by anything?

(*Mr Meacher*) Yes it has. The Inter-Agency Committee on Global Environmental Change was set up—and I will ask David Fisk to respond because he is much more involved than I—because of the fragmentation in the bodies which were providing the research. For reasons that I have already indicated, I think that has been significantly improved. It did have the key role of producing a UK strategy for global environmental research. I think it has fulfilled that role. It was examined by the Chief Scientific Adviser's Committee and it was decided—and I am quite happy to believe this was the right decision—that it should be brought to a conclusion, but it has been replaced by the Global Environmental Change Committee which is chaired by David Fisk, and I am sure he will be delighted to tell you more.

157. What is the difference?

(*Dr Fisk*) The original committee, you will recall, was created in the time of the Advisory Board of the Research Councils which was a very different pre-*Realising Our Potential* country, and at that time the global environmental change research programmes were dissipated over eight or nine institutions, at least, and had never been brought together in any single form before. There was clearly an urgent need, which was recognised by the Chief Scientific Adviser of the time, that some process should be put in place that made sure that the ABRC took the appropriate decisions cognisant of what was going on in other areas and also making sure that the various elements of research did not fall down the proverbial cracks between research councils. What happened, of course, in *Realising Our Potential* is that a number of issues were reconsolidated in the NERC, probably the most important being that the earth observation programme was moved away from what was then the Science and Engineering Research Programme into the NERC programme, so the NERC now has a really quite coherent single focus on the whole of the earth's systems process which was not there before. It still has relations with the MRC and BBSRC but it has a much more coherent programme. Chairman, you could say that I am bound to say that as I am a member of the NERC Council, but certainly our perspective is that we have a much more coherent picture in that process. The IACGEC produced a number of reports. Among the most important was the work of a task force chaired by the Professor Brian Hoskins, which is usually called the Hoskins Report, which was a review by the task force across the whole area of global environmental change looking at some of the key areas. The IACGEC under the Chairmanship of Professor Sir Richard Southwood allocated the responsibilities for carrying forward each one of those elements. That has not been done in some countries. Some countries are still running almost unco-ordinated programmes, so we do already have this process. When it was reviewed by the Office of Science and Technology it was recognised that with the more centralised NERC programme it was more appropriate for the IACGEC to be replaced by something which was slightly less bureaucratic and more directed towards, shall we say, organising coherence with some of the policy outcomes, which I will mention, if I may, in a moment. One of the changes is that we now have the Royal Society co-opted on to the Committee, so we have another dimension which is the Royal Society's representation of United Kingdom programmes in the wider International Council of Scientific Unions which was not represented before. That is an improvement in that respect. Having said that, we have met once because we were only formed about a month or so ago, but what we have already done is reaffirmed that the attributions and responsibilities in the Hoskins Report will serve through the current spending review. What we are now constructing is a decade calendar of the major international events which will address global environmental change issues of one form or another, which is trying to

[**Dr Jones** *Cont*]

improve the impact of UK science in those events. We are very conscious that this works extremely well in the climate change process, but there is a whole set of other issues, biodiversity we have mentioned, the "Rio Plus Ten" Summit, and so on, which could have a very similar result by helping the scientific community to focus on those processes. When we have got through that piece of work we will be ready to look at the next spending review and see how those programmes come together. The view we took when we were polling opinions was very much the one the Minister has just spoken to, which is a recognition that you could "over-cohere" here in this area. It is perfectly plausible for the NERC to be helping out in the development of some views of ocean models which would be more helpful to, let us say, American climate modellers than it might be for ourselves, but this is an international scientific effort and it is more important to make sure that we are understanding what we are doing and communicating and co-ordinating together than produce a man-on-the-moon-by-Christmas type of programme, which is very likely not to address the sort of dissident issues you were addressing earlier which are really rather important in this area.

Dr Turner

158. Michael, can I bring you back to the possible very large reductions of CO_2 emissions which we are agreed quite soon will be needed. Would you agree that, if those are going to be achievable, it would require a tremendous shift in energy production from carbon fossil fuels to renewable sources and that, if we are going to do that in the foreseeable future, we need to be making a prodigious effort now and not in a few years' time?

(*Mr Meacher*) I completely agree with that. The requirements are basically a fundamental change of mobility in modern societies towards vehicles with ultimately zero emissions towards more efficient fuel standards, enormous improvements in energy efficiency and, as you have said, a fundamental and accelerating shift away from fossil fuels, oil and coal, towards renewable sources of energy—wind-powered, biomass and ultimately solar power.

Chairman

159. The Geological Society did suggest the Government has not adequately addressed the implications of rapid short-term changes in weather and climate caused by large volcanic eruptions and pointed out these could, even in this country, lead to a significant cooling with severe adverse effects on agriculture and political and economic results which would be unacceptable and difficult to manage. Does the United Kingdom have any disaster or emergency planning contingencies for such an event, something which might be called a "volcanic winter". Even though we do not have volcanoes, you yourself, Minister, have alluded to things that have happened in Indonesia and Krakatoa and elsewhere. Is this something that we do plan for?

(*Mr Meacher*) The current position is that natural disasters are dealt with through the central/local partnership (that is between central government and local authorities), but in the light of severe weather impacts, most recently of course the mass flooding and the expectation that it will recur and possibly get worse, we are reviewing those processes and it may well be the very fact of such dramatic impacts being visited upon us more frequently and in perhaps unpredictable ways over the next decade—and it is very difficult to respond to events that cannot yet be accurately predicted—that we shall discover that the existing mechanisms are not really geared to what for this country is a completely novel experience.

Dr Jones

160. What efforts are being put in to manage the regional impacts of climate change and are local government bodies and regional agencies getting the right advice? What is the relationship between your own department and other government agencies in local government?

(*Mr Meacher*) We did set up the United Kingdom Climate Impacts Programme and that has produced a number of regional scenarios of climate change in the case of the North West, the South East and the East Midlands and in terms of the devolved administrations of Scotland and Wales, and the other regions are, I understand, either being planned now or are underway. I have launched a couple of these along with the authors and I think they are very good. They are detailed, they are specific, and I think they do have clear recommendations of the changes that are necessary as well as the unexpected and unpredicted changes which up to now I think most people have not contemplated. The United Kingdom Climate Impact Programme 1998 climate change scenarios were sent by DETR to all local authorities. We have said that we will be helping local authorities develop strategies to adapt to climate change as well as, of course, to assist them in cutting greenhouse gas emissions. The emphasis is now on this balance between trying to prevent further greenhouse gas emissions, to try and restrict this up to now inexorable growth, although we can only do that internationally. We are already sufficiently far down the track that we have to put a lot of emphasis and policy-making into trying to adapt. The floods are the best example and the action in terms of the flood plains. The Government over the current year is putting £400 million into planning to prevent disasters resulting from floods. Many people think that that is not enough. Adaptation is increasingly the central item immediately on the Government's agenda but we must not lose sight, of course, of the long-term aim internationally together with other countries, of reducing greenhouse gases globally.

161. Thank you very much indeed, Minister, for a most interesting 75 minutes. We have enjoyed putting the questions to you and receiving your answers and we hope it has not been too unpleasant an experience for you. You seem to have survived it extremely well. We are very grateful, too, to Dr Fisk and Mr Warrilow for coming along and supporting you. We look forward to a letter from Mr Warrilow in due course. We hope, Minister, that you will find our report interesting, not just the summary of it but the whole report in due course (if it is allowed to get to you!) because it will be our view on how the whole

[Dr Jones *Cont*]
of the scientific advisory system is operating in government. You have helped us with one chapter of it, albeit a significant chapter, and we hope the Report will be of some help. Once again, we thank all three of you for being with us this afternoon.

(*Mr Meacher*) May I say on my side that we take the reports of all the select committees very seriously and I know that from the effort that goes into it and the care with which I look at the main recommendations, but I think this particular Committee has already established a very significant reputation certainly with what you said in regard to GMOs and I am expecting the same high standards and also an earnest and urgent response from the Government.

Chairman: Thank you very much indeed.

Supplementary memorandum submitted by Mr David Warrilow, Head of Science Policy, Global Atmosphere Division, Department of the Environment, Transport and the Regions following the evidence session of 20 December 2000

We undertook to advise the Committee on the disciplines of scientists working at the Hadley Centre and those that they worked with. The Committee also asked us to give an indication of our plans for the future.[2]

Of the 78 graduates at the Hadley Centre, the majority have degrees in maths and physics with a few in environmental science, geography and other related disciplines. One member of staff has an MSc in Ocean Biology and Physics. This is largely to be expected as the predominant work of the Hadley Centre is and has been physical process modelling. Modelling efforts are very largely a mathematical activity. However, over the years the biological processes in the model have been developed in collaboration with the leading six biologists and ecologists at other institutes.

A number of the staff at these institutes are actually funded by DETR through the Hadley Centre and they contribute to the development of biological processes both in the ocean and on the land surface. This has been an effective way of developing biological processes in the model and has so far worked very successfully. The Hadley Centre has been at the forefront of Climate modelling work on the interaction of biological processes on the climate system, including one paper published very recently on carbon cycle feedback in the peer reviewed journal *Nature.*

Our plans for the next two years retain this approach. We will be developing the biological processes further and will continue to work in partnership with experts in other organisations. If a clear need for intramural staff with expertise in the biological sciences arises then we will of course address that.

26 January 2001

---

[2] Q133.

APPENDICES

APPENDIX 1

Memorandum submitted by RJB Mining (UK) Ltd

RJB Mining (RJB) welcomes the opportunity to provide a submission to the Science and Technology Committee's investigation into Scientific Advice on Climate. RJB Mining (RJB) is Europe's largest unsubsidised coal mining company. It is also Europe's lowest cost deep-mine operator. The Company currently employs over 7,000 people at over 40 locations throughout the UK. RJB produces about 60 per cent of all the coal mined in the UK, from 13 deep-mines and a similar number of opencast sites.

RJB has a keen interest in the debate on climate change. Coal has the highest carbon content of all fossil fuels and hence is seen as both the cause and answer to "global warming". RJB believes that UK coal should continue to play its part within the Government's energy policy of secure, diverse and sustainable supplies of energy at competitive prices. It is therefore essential that before any evidence is presented to Government which could adversely affect the role of coal within world energy, all research has been critically appraised and potential alternative explanations are presented for consideration. The concept of "climate change" has gathered momentum in recent years and it now appears that it is readily used as the cause for any damage caused by the weather.

RJB notes that the DETR in its publication "Climate Change and its Impacts", October 1999, states that the global mean surface temperature in 1999 will be substantially cooler than the record year of 1998, although still likely to be one of the highest 10 on record. The understanding and predicting of weather conditions is a complex subject. The cause of the warming trend over the course of this century is still not fully understood. As evidence shows, the climate fluctuated naturally long before industrialisation of the planet and it is possible that we could again be on a natural temperature cycle.

The UK Government have been at the forefront of promoting greenhouse gas reductions worldwide. In the foreword to the above document, the Secretary of State for the Environment Transport and the Regions states that "evidence is mounting that mankind is affecting the global climate". Within the document no firm evidence is presented, but it goes on to present a series of predictions for the next 350 years which the DETR appears to take as fact. There are no assumptions given and more importantly no warnings as to the uncertainty of the science involved.

RJB does not wish to be viewed as a Luddite in the area of climate change. It believes that all emissions to atmosphere should be kept to a minimum. To this end, RJB has been trying to obtain funding from the Government for the next generation of clean coal power plant which would reduce CO_2 emissions by up to 30 per cent, to date without success. However, it is important that a balanced view is presented in all Government documents, recognising the complex nature of the science concerned.

13 January 2000

APPENDIX 2

Memorandum submitted by the Institution of Professionals, Managers and Specialists (IPMS)

INTRODUCTION

1. The Institution of Professionals, Managers and Specialists (IPMS) is a trade union representing 74,000 scientific, technical and specialist staff in the Civil Service, research councils, other public sector bodies and an increasing number of private sector companies. IPMS submitted evidence to the Committee's inquiry in May 1998 and, in March 1999, to the case study on genetically modified foods. This brief submission supplements our earlier evidence and is based on the experience and expertise of members directly involved in providing advice on climate change. For example, IPMS members are involved in the Terrestrial Initiative on Global Environmental Research, the Land Ocean Interaction Study, and the Environmental Change Network.

2. Across a broad area of expertise, IPMS members see little reason to doubt the position of the Intergovernment Panel on Climate Change (IPCC) on upward changes in temperature and CO_2 emissions. They emphasise that the overwhelming majority of informed scientists consider that climate change is substantially anthropogenic and that the internationally agreed mitigation strategies are crucially important. Indeed, divisions in this area tend to be somewhat artificial; with objectors drawn mainly from petrochemical companies and certain economic think-tanks, supplemented occasionally by maverick scientists from the USA. Accordingly, the way forward lies in further refining existing climate change models and developing mitigation strategies on this basis, not in seeking alternative explanations for climate change.

3. For example, the Natural Environment Research Council's Institute for Terrestrial Ecology (ITE) has been involved for a number of years in providing advice to the Department of the Environment, Transport and the Regions (DETR) on the possible environmental consequences of climate change. ITE has also reported on mitigation strategies involving the use of short rotation and conventional forestry. An important recent step forward is the development of global vegetation models which interface with climate models, such as that developed by the Meteorological Office's Hadley Centre, to predict the likely feedback between climate and associated vegetation change. This work illustrates the value of "joined up" government science and must continue on a fully funded basis.

4. However, there are other areas of work relating to climate change that are less well researched and resourced by government. One such area relates to the impact of climate change on farm or companion animals. There has been only one project funded by the Ministry of Agriculture, Fisheries and Food, on arthropod vector transmission of disease. The strong view of scientists working in this area is that this is because the research agenda has been defined to reflect the priorities of the parts of the Central Science Group that are driving the climate change programme. Some other work on impact on animals has been undertaken, but only on the basis of securing EU funding, and the assessment of our members is that at present this remains something of a "black hole". Therefore, it would appear that although constructive partnerships have developed in some areas, there is still more that could be done to promote a cross-departmental strategic approach.

5. Gaps in communication are also illustrated by the uncertainty of some members as to whether the results of their research are actively considered by policy makers. It would appear that although research findings are often published, for example in scientific journals, it is not clear to staff in the relevant research establishments whether the government is always advised of the implications. This is of concern both to those directly concerned and because it suggests a weak feedback loop between researchers and policy makers. It is also relevant to the conclusion of the Baker Report[1] that more needs to be done to promote knowledge transfer. Although John Baker was concerned primarily with realising the economic potential of public sector research establishments, it is clear that liaison between research providers and departmental, rather than commercial, "customers" does not always work as well as it should either. As IPMS has consistently argued[2], moving science away from the core of departmental decision making exacerbates this weakness. The recent debate about genetically modified organisms has again highlighted the need for a critical mass of scientists in government, both to provide specialist advice and in policy functions.

NOTES:

[1] "Creating Knowledge, Creating Wealth" by John Baker, Medeva Plc for HM Treasury and Office of Science and Technology, September 1999.

[2] Including, most recently, in our response to the Baker Report, copies of which are available on request.

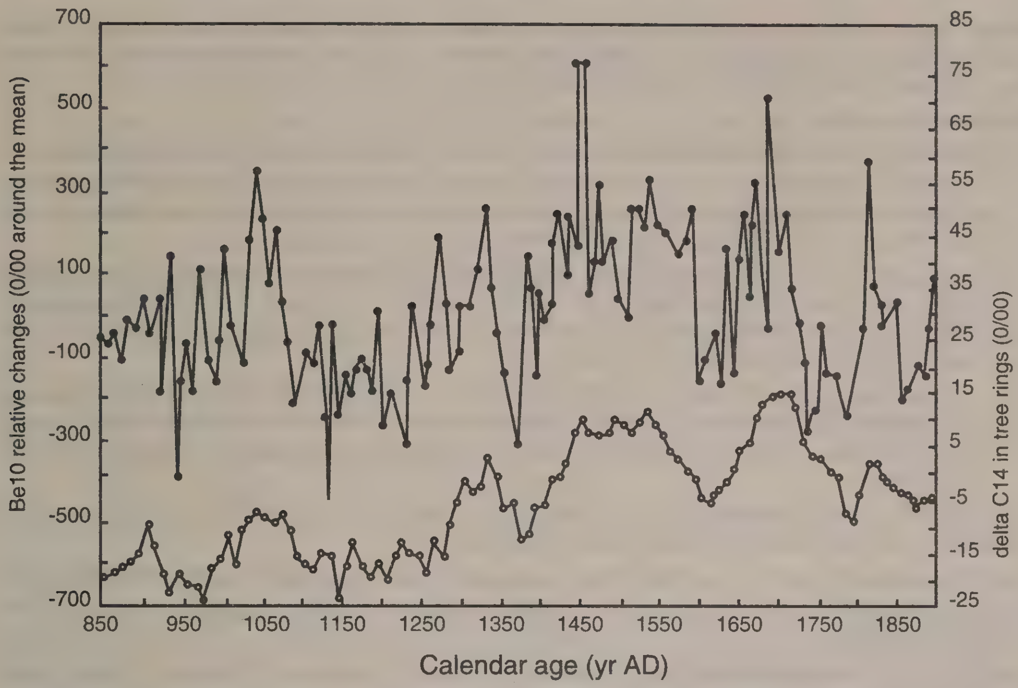
28 January 2000.

APPENDIX 3

Memorandum submitted by the Geological Society of London

The Geological Society of London, founded in 1807, is the oldest geological society in the world. It has 8,800 members world-wide, and is both a learned society and a professional body.

This submission was prepared by Professor RCL Wilson (Honorary Secretary, Foreign and External Affairs), with contributions from Dr Stephen Blake (Open University), Professor Geoffrey Boulton FRS (University of Edinburgh), Lord Oxburgh FRS (President elect, and Imperial College), Professor Sir Nicholas Shackleton FRS (University of Cambridge), and Professor Bob Spicer (Open University). These colleagues and members of the Society's External Relations Board have commented on several drafts. The submission has been approved by the Board.



Changes in atmospheric CO_2 and temperature over the last 400,000 years as recorded in the Antarctic Vostok ice core (lower left box), and atmospheric CO_2 over the last 1,000 years. The caption for this figure is on page 1.

The figure shows data obtained from cores obtained by drilling through the Antarctic ice sheet at the Russian Vostok research station[1]. Variations in temperature above the present day mean of −55.5°C are shown, based on an analyses of the hydrogen isotopes present in the ice. The plot of atmospheric CO_2 content was obtained by analysing bubbles of air trapped in the ice. The small box in the upper right diagram shows the rapid increase in CO_2 caused by the industrial revolution (note that this part of the diagram shows a time span of 1,000 years, whereas the main diagram spans 400,000 years).

The left hand plot in the lower left box shows changes in the amount of solar radiation received at the Earth's surface (insolation) in mid-June at 65° North. Mid-June insolation in northern high latitudes is thought to be the key to the origin of glacial periods. If summers in these areas are cool enough, winter snows will survive, leading to successive annual accumulations of snow and ice. Variations in high northern latitude summer insolation are caused by variations in the shape of the Earth's orbit (eccentricity), the angle of its rotational axis (obliquity) and precessional changes. The increase in insolation that commenced about 20,000 years ago triggered the end of the last glaciation. Insolation in northern high latitudes has now almost returned to the level it was 20,000 years ago, but as yet the climate system has not responded to this change.

SUMMARY

The underlying theme of this submission is that an essential ingredient of the "critical appraisal" referred to in the second aim of the case study is to learn from the past to illuminate the future. The Society has four areas of concern which it hopes the Committee will investigate; these are summarised below:

I. The extent to which knowledge and understanding of past changes in climate and atmospheric composition have contributed to the development of scenarios of future change considered by the Government.

Key aspects of such knowledge and understanding are that geological data:

- provides the only information we have about how the Earth's climate system has behaved over meaningful lengths of time (ie hundreds of thousands of years, in contrast to reliable historical records which only extend back about 150 years);
- provides a record of changes in atmospheric composition before anthropogenic influences took effect;
- shows that the Earth's climate system may flip rapidly (in decades) from a colder to a warmer mode;
- shows that sudden releases of carbon into the atmosphere (comparable in size to that being caused by the burning of fossil fuels and other anthropogenic causes) are only removed slowly over tens of thousands of years.

II. The extent to which Government ensures that the climate modelling studies used to predict global and regional climate changes are evaluated by testing their ability to replicate past climate changes that occurred in both greenhouse and icehouse worlds.

The Society's key concerns are:

- that climate models have inherent limitations due to their ancestry in models designed to predict the behaviour of today's weather systems, and because they have to simplify an exceedingly complex climate system in which processes operating in the atmosphere, oceans, ice sheets, and solid Earth are linked together;
- the models are unable to fully replicate past climates during periods when the Earth was much colder, and much warmer, than it is today. The flaws are most marked in reproducing conditions in continental interiors during greenhouse climates that characterised much of the Earth's history over the last 500 million years;
- therefore continued comparison of model simulations with geological data about past climates are required to inform the design of improvements necessary to provide more reliable predictions about future global and regional climate changes forced by rising atmospheric CO_2 levels.

III. The extent to which Government has addressed the implications of rapid short term changes in weather and climate caused by large volcanic eruptions.

Historical and geological records show that large eruptions can cause significant cooling at regional and global scales resulting in "volcanic winters" that could have severe agricultural, economic, and political implications.

IV. The extent to which Government seeks the views of a broad range of scientists in addition to the advice given by its appointed advisers and consultants.

INTRODUCTION

1. It is natural that the institutions directly concerned with current weather and climate should be consulted over climate change. However, reliable climate records go back little more than 150 years—a mere blinking of the eye in the hundreds of millions of years of Earth history. Humanity's activities may well be triggering changes in the present climate, but to understand the extent to which similarly large changes may have occurred in the past without anthropogenic intervention, it is necessary to look at past climate changes as recorded in the geological evidence—especially in the sediments of the deep oceans and in ancient ice sheets. It is not clear that the Government has sufficiently taken advantage of the work of geological specialists in these areas. In the pages which follow we elaborate the contribution that studies of this kind, combined with others, may make to understanding changes in the Earth's climate.

2. This submission focuses on the second aim of the case study, namely to identify "what critical appraisal there has been of models predicting climate change, increasing concentrations of carbon dioxide, and other potential drivers". The underlying theme is that an essential ingredient of such "critical appraisal" is to learn from the past in order to illuminate the future. To do this scientists use their understanding of the Earth's climate system to interpret the information they collect from fossil climate indicators (often referred to as proxy climate data).

3. Historical records indicate the extent of climate change over the last few centuries, but a pattern of repeated climate change is only revealed by examining the geological record. The mechanism by which the climate system may change can be demonstrated by correlating observed effects preserved in the geological record with postulated causes. Usually this only leads to a qualitative understanding, which does not yield many insights concerning changes in the interconnectivity between different components of the climate system. Palaeoclimatologists obtain a deeper quantitative understanding by using computer generated climate models both to aid their interpretation of proxy climate change data, and to explore the possible effects of changes in different climatic forcing agents. Increasingly geological techniques permit a quantitative record of climatically determined parameters to be reconstructed through time. Although this does not directly indicate the causes of change, correlations between measures which reflect different climatic variables can suggest causality. Palaeoclimatologists can, by using computer generated climate models, attempt to simulate this geologically inferred behaviour and thereby test their theories of the causes of climate change. This use of models is often overlooked in debates about possible future climate change.

4. The only way to predict how the climate would change in the absence of anthropogenic effects is to understand the nature of past climate variability over decadal to millennial time scales. Likewise, the evaluation of climate models used to predict climate change can most convincingly be made by determining the extent to which they can fully explain what happened in the past (ie be used to "retrodict", rather than predict, the future).

5. The first aim of the case study is to identify "the extent to which the Government has been advised of potential alternative explanations, how these alternatives have been assessed, and what conclusions have been drawn". The Society is not in a position to make such judgements without being able to question directly ministers, their civil servants, and advisers, directly. However, the content of the recent Sir Peter Kent Lecture

given to the Society by Michael Meacher[2] does indicate that the Government is well aware of many of the conclusions that can be drawn from evidence of climate change contained in the geological record. Nonetheless, we suggest that the committee investigates the extent to which Government:

- — ensures that models used to predict possible future global and regional climate changes are evaluated by testing their ability to replicate past climatic conditions based on palaeoclimatic indicators;
- — seeks the views of a broad range of scientists in addition to those who provide information and advice as appointed advisers and consultants.

6. Our comments on the second aim of the Committee's inquiry are given below under the following headings:

- — CO_2 and climate change
- — Natural climate variability
- — How long might it take for atmospheric CO_2 levels to return to normal levels?
- — Climate modelling and the geological record
- — Volcanic winters.

CO_2 AND CLIMATE CHANGE

7. Air bubbles within Antarctic ice enable changes in the CO_2 content of the atmosphere to be determined for the last 400,000 years (see cover figure). During the four warm interglacial periods similar to those the Earth has experienced for the last 10,000 years, atmospheric CO_2 content reached 270–280 ppm, and during the coldest parts of glacial periods, this dropped to 190–200 ppm. Changes in atmospheric CO_2 are closely correlated to changes in temperature.

8. What is the link between atmospheric CO_2 content and temperature change? Does increasing temperature cause carbon dioxide to be released from the ocean, thereby increasing atmospheric concentration, or does increasing carbon dioxide cause temperature increase because of the greenhouse effect? We know that both processes occur. If the greenhouse effect (which is due not only to the presence of CO_2 in the atmosphere, but also water vapour and methane) did not occur on Earth, its surface temperature would be 30°C colder, and life as we know it would not exist. Equally, we know that warm tropical oceans exhale carbon dioxide, whilst cold polar oceans inhale carbon dioxide.

9. It is probable that the close correlations shown in the cover figure reflect close coupling of temperature and carbon dioxide, ultimately forced by changes in the amount of solar radiation reaching the Earth's surface (see second part of figure caption). If this increases and causes a rise in the Earth's surface temperature, there is net exhalation of carbon dioxide from the oceans, atmospheric CO_2 increases and further greenhouse warming occurs. This in turn increases carbon dioxide exhalation, and so on, in a positive feedback loop. The reverse process follows reductions in radiation received at the surface. The question for the past is how do positive feedback loops involving carbon dioxide and temperature come to be stabilised at the glacial and interglacial levels shown in the cover figure. We do not know the answer. The question for the future is what sort of feedback loops might result from anthropogenically driven increases in atmospheric CO_2. Once again we do not know the answer.

NATURAL CLIMATE VARIABILITY

10. Geological and historical records show that climate change has occurred over a range of time scales, from the very slow (over millions of years) to very fast (over a few decades). The cover figure shows that over the last 400,000 years, climate has varied between cold glacial periods, and warm interglacial interludes such as the one we enjoy today. These warmer conditions only persisted for about 10 per cent of this period of time.

11. During the last glacial period (between 10,000 and about 110,000 years ago) there were 24 warmer interludes[3]: each cool-warm cycle lasted for about 1,500 years. The asymmetry of changes of temperature between the cooler and warmer interludes mirrors that which occurred over the four glacial cycles shown in the cover figure: slower stepwise cooling followed by rapid warming. This suggests that the climate system may flip rapidly from one state to another.

12. During the present and last interglacial periods, global temperatures were relatively stable compared to glacial periods. There is, however, some evidence to suggest that during the current interglacial there were regular changes in climate in the North Atlantic area with a periodicity of about 1,500 years[4,5]. These were pale shadows of much greater changes that occurred during the last glacial period. One manifestation of these changes occurs as peaks in the delivery of ice rafted debris into the North Atlantic—during colder parts of the 1,500 year climatic cycle icebergs almost reached Ireland. These temperature fluctuations were sufficiently large (about 2°C) that, if they occurred in the future, they would have significant effects on agriculture. The "Little Ice Age" (which lasted from late medieval times until the 19th century) was the last of these cooler episodes. Warming since it ended is likely, therefore, to be due to a combination of "natural variability" and the anthropogenically driven portion of the greenhouse effect.

How Long Might it Take for Atmospheric CO_2 Levels to Return to "Normal"?

13. Since the beginnings of industrialisation at the end of the eighteenth century, the anthropogenic source of carbon dioxide has released approximately 310 gigatonnes of carbon into the atmosphere: 260 GtC (1GtC = one thousand million tonnes of carbon) from fossil fuel and cement production, and 50 GtC from terrestrial ecosystems, mainly due to changes in land use practices. It has been estimated that whereas 140 GtC of this anthropogenic output has been absorbed by the oceans, 170 GtC has accumulated in the atmosphere, with the consequence that the atmospheric concentration has reached a level unprecedented for an interglacial period (ie 360 ppm instead of the normal proportion of 280 ppm). It is increasing at a rate of 0.4 per cent per annum. Although we expect carbon dioxide and temperature to be coupled in a feedback loop, as seems to be the case with respect to past natural variations, we do not understand how and at what level a future equilibrium will be reached. However, the geological record does indicate how long it might take for atmospheric CO_2 levels to return to their normal level if anthropogenic releases of CO_2 were to cease immediately.

14. Current estimates suggest that in less than a thousand years, human activity will add 2,000–4,000 GtC to the atmosphere. Until last year, the only means of evaluating the possible climatic consequences of this huge release of carbon was to use modelling studies. However, the recent discovery that a huge blast of carbon into the atmosphere occurred 55 million years ago gives new insights not only into the nature of the global carbon cycle, but also how long it may take for the Earth's system to return to equilibrium after such a blast.

15. The new work[6] has shown that for a brief period 55 million years ago, temperatures in the deep oceans and at high latitudes rapidly increased by 5–7°C. Although the cause of this warming is not clear, geochemical evidence from deep-sea sediments indicates that over 1,000 GtC was released into the ocean and atmosphere. This was probably due to the release of methane from gas hydrates (a frozen form of methane plus water that is stable in low temperature and high pressure conditions) present in sediments along outer continental shelves and continental slopes. This injection of carbon occurred over less than 10,000 years, but it took 140,000 years for it to be absorbed. This suggests that if the global carbon cycle operated in a manner similar to the way it does today, we will have to wait an exceedingly long time for atmospheric CO_2 levels to return to their normal interglacial levels. It should be borne in mind, however, that the Earth was much warmer 55 million years ago, so it is likely that, because the climate system operated in a different mode, rates of carbon sequestration may not have been the same as those of today.

Climate Modelling and the Geological Record

16. All sophisticated climate models currently in use are based on weather forecasting models and by definition are designed and tuned to reliably simulate the present atmospheric processes and conditions. Moreover, they do not attempt to simulate all aspects of climate system processes, but employ a range of "short cuts" designed to give realistic results for our present world. Simulation and sensitivity modelling aids our understanding the causes of past climate change, and the possible variations that await us in the future, but the nature of the models has to be borne in mind when interpreting results of experiments designed to simulate globally warmer conditions.

17. Despite the development of ever more sophisticated climate computer models, the problem that still has to be faced is that apart from at the last glacial maximum 18,000 years ago, there is not enough high resolution palaeoclimate data available from enough locations around the world on which to base computer driven simulations of past global climate systems. For this reason, many climate modelling studies use simplified algorithms rather than trying to reproduce every detail of a past global climatic episode. In other words, models are used to explore the sensitivity of the climate system to changes in specific forcing factors, such as changes in the proportion of greenhouse gases in the atmosphere, or the distribution of land and sea around the Earth.

18. The more ambitious simulation models require that quantitative definitions of various components of the climate system are fed into the programme, such as incoming solar radiation, reflectivity (albedo) of land, sea and clouds, the extent of ice sheets, deep and surface oceanic temperatures, and the CO_2 and water vapour content of the atmosphere etc. These general circulation models (GCMs) can only be run on very large supercomputers, and until recently, most of them could only treat the oceans as a "wet carpet", and did not simulate shallow and deep circulator patterns. Producing models of regional and global oceanic circulation is also a complex task but significant progress is being made. The reliability of the predictive output of simulation models can be assessed by comparing their outputs to present day temperature and wind patterns. However, geologic evidence shows the present world is abnormally cold in comparison to what it has been for most of the past 500 million years. If the world is indeed warming, therefore, then it is vital that the models can operate reliably for such greenhouse conditions. When existing models are used to produce simulations of past climates, say, during the Late Cretaceous (99 to 65 million years ago), or for the Eocene (55 to 34 million years ago) when global mean temperatures were 10°C higher than today, they do not perform well. In particular continental interior climates are predicted to have been markedly colder and drier compared to what a plethora of geological evidence shows to have been the case[7,8]. These errors are similar, irrespective of which model is used, or which assumptions are made about the atmospheric or geographical conditions during those times. The models are demonstrably more reliable for cool world scenarios than for those for

warm worlds. This may reflect the modern day origins of the models, and the intensive comparisons with data obtained from glacial periods.

19. The implications for successfully modelling future possibly warming point to the need to take heed of geological data. Once we have models that satisfactorily simulate present and past observations of the behaviour of the atmosphere, oceans and ice sheets, the next step is to couple them together to refine simulations of possible past climatic conditions, and to predict more confidently future climatic changes. Such advances will require not only more sophisticated simulation models, but a greatly improved knowledge of past global climate change obtained from the geological record. Crucial to this appraisal of model predictions (and retrodictions) is to compare their results with extensive geological observations. The latter can only be obtained by co-ordinated international efforts in order to make the increasingly critical tests of model predictions that Government and the international community require.

VOLCANIC WINTERS

20. Historical records reveal that anomalous weather and climatic effects (volcanic winters[9]) have occurred for several years following a number of large volcanic eruptions. Such effects involve not just the environs of the volcano, but can have a significant impact on the regional, hemispheric or global scales.

21. The connection between lowered temperature and volcanic eruptions is due to the effects of sulphur dioxide gas released during explosive eruptions. In sufficiently powerful eruptions, volcanic rocks and gas are lofted into the upper atmosphere where the volcanogenic sulphur dioxide gas reacts with water to form micron-sized droplets of sulphuric acid gas. These aerosol droplets have the principal effect of reflecting incoming solar radiation. Consequently, the temperature of the lower atmosphere is reduced over the period taken for the aerosol to be chemically and physically destroyed.

22. For example, a powerful eruption of the Indonesian volcano Tambora in 1815 was followed by one to two years of unusually cold climate around the world. In Europe, annual mean temperatures were 1 to 2.5°C lower than normal, harvests were either late or failed altogether, grain prices were at their highest and famine was widespread. During the summer of 1816, the USA experienced a widespread snowfall. The annual global mean surface temperature was about 1°C below normal. The years 1816, 1817 and 1818 had some of the coldest Northern Hemisphere summers on record[10-12].

23. Two further examples are the 1783 eruptions of Laki in Iceland that led to a "dry fog" permeating much of western Europe and large parts of north America, where average 1783/4 winter temperatures were up to 4.8°C below the long term average[13], and the 1991 eruption of Pinatubo (Philippines) with a 0.4°C fall in mean global surface temperature in 1992[14]. Eruptions that have a short term influence on climate occur irregularly but by no means infrequently. At least six such eruptions occurred in the 20th century.

24. The Tambora eruption in Indonesia that occurred about 70,000 years ago was one of the largest to have occurred over the past few hundred thousand years[15]. It occurred during a period of rapid cooling from interglacial to glacial conditions. Ice core records indicate that huge amounts of volcanic dust and aerosols that it injected into the upper atmosphere may have remained there in significant amounts for up to six years. This may have caused global cooling between 3 and 5°C, and perhaps as much as 10°C during growing seasons in middle to high latitudes.

25. Given the climatic impact of volcanic eruptions described above, and the likelihood of future eruptions, the Society recommends that the Committee investigate the extent to which the Government has explored the agricultural, economic and political consequences of volcanic winters.

CONCLUSIONS

26. The geological record provides relatively high resolution information about climate changes that have occurred over the last few hundred thousand years. This shows that there is a link between global temperatures and the greenhouse gas content of the atmosphere, but, as yet, the extent to which the latter is the cause of the former is uncertain. Palaeoclimatic records also show that global average temperatures have fluctuated by as much as several degrees in a matter of decades. Although climate models have yet to successfully simulate changes in the atmosphere-ocean-ice sheet system that result in such rapid shifts, our understanding of the system is sufficient to argue strongly for the precautionary principle to be applied in favour of reducing anthropogenically induced greenhouse gas emissions. Opponents of this approach argue that we should postpone taking effective steps to reduce these until such time as research can convincingly demonstrate the climatic impacts of emissions, and distinguish natural climatic changes from human induced ones. This implies a rather naïve faith in science to deliver certitudes. We will only obtain "proof" as the global experiment we are conducting unfolds. If this experiment triggers a rapid reorganisation of the climate system, proof might come too late for preventative action. In the meantime, continued investment in research into past climates will be crucial to providing rigorous tests of the likely effects of anthropogenic intervention into the workings of the Earth's climate system.

REFERENCES

1. Petit, JR, *et al,* Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Nature, 399, 429–436 (1999).

2. Meacher, M, Ice age or global warming—which is it? Geoscientist 10/1, 16–17, (2000).

3. Bond, G, *et al,* Correlation between climate records from North Atlantic sediments and Greenland Ice, Nature, 342, 637–42 (1993).

4. Bond, G, *et al,* A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. Science, 278, 1257–1265 (1997).

5. Campbell, ID, *et al,* Late Holocene 1,500 yr periodicities and their implications. Geology, 26, 471–473 (1998).

6. Dickens, GR, The blast from the past. Nature, 401, 742755 (1999).

7. Greenwood, RR, and Wing, SL, Eocene continental climates and latitudinal temperature gradients. Geology, 23, 1044–1047 (1995).

8. Valdes, PJ, Spicer, RA, Sellwood, BW and Palmer, DC, Understanding Past Climates: Modelling Ancient Weather. CD ROM, Gordon and Breach, Reading, UK (1999).

9. Rampino, MR and Self, S, Volcanism and biotic extinctions. In: Encyclopedia of volcanoes (Ed: H Sigurdsson), Academic Press, San Diego, 1083–1091 (2000).

10. Lamb, HH, Climate, History and the Modern World, 2nd Edition, Routledge (1995).

11. Stothers, RB, The great Tambora eruption in 1815 and its aftermath. Science, 224: 1191–1198 (1984).

12. Briffa, K, *et al,* Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years. Nature, 393, 450–455 (1998).

13. Sigurdsson, H, Volcanic pollution and climate: The 1783 Laki eruption. Eos, Transactions of the American Geophysical Union, 63(32) 601–602 (1982).

14. McCormick, MP, *et al,* Atmospheric effects of the Mt Pinatubo eruption. Nature, 373: 399–404 (1995).

APPENDIX 4

Memorandum submitted by the Biotechnology and Biological Sciences Research Council

INTRODUCTION

1. The Biotechnology and Biological Sciences Research Council (BBSRC) was established by Royal Charter in April 1994. It is a non-Departmental public body principally funded by the Department of Trade and Industry via the Office of Science and Technology and through the Science Budget. BBSRC-sponsored Institutes receive a proportion of their funding from the Ministry of Agriculture, Fisheries and Food (MAFF) by means of research commissioned on a consumer/contractor basis and research support from other Government Departments, the EU and industry.

2. The Council's mission is:

- to promote and support high quality basic, strategic and applied research and related post-graduate training relating to the understanding and exploitation of biological systems;
- to advance knowledge and provide trained scientists and engineers which meet the needs of users and beneficiaries (including the agriculture, bioprocessing, chemical, food, healthcare, pharmaceutical and other biotechnology-related industries) thereby contributing to the economic competitiveness of the UK and the quality of life; and
- to provide advice, disseminate knowledge and promote public understanding in the field of biotechnology and the biological sciences.

3. Research is supported through responsive mode grants to universities and academic analogues and through provision of the Competitive Strategic Grant (CSG) to the BBSRC-sponsored Institutes.

ACTIVITIES IN CLIMATE CHANGE

4. BBSRC research on climate change has largely been focussed on the effects of change on microbes, plants and animals, the potential impact on UK agriculture and strategies for mitigation. The Agriculture and Food Research Council (AFRC) initiated a programme in Biological Adaptation to Global Environmental Change (BAGEC), which was taken up by BBSRC during re-structuring. The programme ran in parallel to the Natural Environment Research Council's (NERC) TIGER (Terrestrial Initiative in Global Environment Research) programme. It provided support for research in the following areas, relevant to agricultural systems:

- the interaction between biological processes (plant, animal and microbial) and fluxes (energy, water, nutrients, gases) which influence climate;
- the impacts of climate change on plants, animals and microbes at the molecular, cellular, whole organism and population levels, and;
- the response measures that can be taken to deal with such changes.

5. The programme was launched in 1992 at a cost of £8 million over four years. In March 1997, at the end of the programme, BBSRC held a dissemination event to communicate results and conclusions to Government, the user community, other scientists and the media.

6. Aspects of the programme have been taken forward under the initiative "Resource Allocation and Stress in Plants" which provides support of £3.7 million over three years.

7. In preparing this response, views were sought from Horticulture Research International (HRI) and the following BBSRC-sponsored Institutes engaged in research relevant to climate change: Institute of Arable Crops Research (IACR), Institute of Grassland and Environmental Research (IGER), and Silsoe Research Institute (SRI).

8. IACR includes within its portfolio work concerned with the impacts of climate change on agriculture and the associated environment and possible mitigation measures involving changes in land management. The main topics of research are: climate change impacts on crop production; opportunities for carbon sequestration in soil through changes in land management; production of biofuel crops to replace some fossil fuel use; effects of agricultural practices on fluxes of the trace gases nitrous oxide and methane, and the UK Environmental Change Network.

9. Research at the Institute of Grassland and Environmental Research relates to the entire production cycle for grassland-related agriculture. It includes studies on soils, plants, animals and microorganisms and covers both mechanistic and systems studies and integration with the needs of industry. IGER North Wyke is also a participant in the Environmental Change Network.

10. Silsoe Research Institute supports innovative research in engineering, mathematics and physics for the agri-food industries. Its business falls into four main areas: environment, crop production, livestock and engineering for hygienic food processing.

11. Work on climate change at HRI has focused primarily on the response of horticultural crops and systems to components of climate change, for example UV-B.

12. BBSRC Office provides input into climate change policy through its membership of the Inter-Agency Committee on Global Environmental Change (IACGEC) and the Cross-Council Group on Climate Change (CCGCC).

13. IACGEC was established in 1990 by the Government's Chief Scientific Advisor and NERC provides the secretariat. The Committee provides UK agencies funding GEC research with a forum for discussion of relevant science and policy developments. It published a national strategy in September 1996 and made a report to the Chief Scientific Advisor in November 1999.

14. CCGCC was set up following the closure of the Global Environmental Research (GER) Office in March 1998. The GER Office had been established in 1990 in recognition of the growing national and international interest in GER issues and the need to coordinate UK responses to research opportunities and challenges across the Research Councils. In taking the decision to close the Office, it was recognised that as GER has expanded to address impacts and solutions as well as detection and understanding of change, there would still be a need to coordinate activities, hence CCGCC was established. CCGCC ensures a collective brief is provided for activities such as the International Group of Funding Agencies (IGFA) and is charged with taking forward recommendations of IACGEC, as required.

The Extent to which the Government has been Advised of Potential Alternative Explanations, How these Alternatives have been Assessed and What Conclusions have been Drawn

15. Results from BBSRC supported research are published in international, peer-reviewed scientific journals and reported at conferences and, in some cases, in media interviews or articles in the popular scientific press or agricultural press. All of this work will be accessible to Government advisors. It would be anticipated that relevant data would be incorporated into high-level models.

16. Government Departments, such as MAFF or DETR, commission work at BBSRC-sponsored Institutes. In addition to scientific publications, results from these projects are written up in the form of reports to the funding body, thus the Department concerned receives rapid and direct information on the findings.

17. Scientists from IACR have participated in the Intergovernmental Panel on Climate Change (IPCC) "Carbon dioxide emissions from soil: national inventories working group" and Working Group II of the IPCC "Climate Change 1995—Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses". Specifically, they have contributed to:

- The 1996 IPCC Revised Guidelines for National Greenhouse Gas Accounting.

- The Special Report on "Forestry Land Use and Land Use Change" due for publication in 2000. This is a key document that translates scientific information into policy options for Government.
- Climate Change 1995—Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses, IPCC Working Group II Second Assessment Report, 1996.

18. The UK Environmental Change Network was established in 1992 and now comprises 12 terrestrial and around 30 freshwater sites. The objective is to monitor environmental changes, including climate and pollutants, and measure their impacts on ecosystems. IACR-Rothamsted is one of the terrestrial sites at which a standard set of measurements is made regularly using standard protocols. Many of the terrestrial sites have long histories of similar monitoring, some of the records at Rothamsted go back over 150 years. Undertaking current monitoring and related research within the context of well-characterised long-term sites maximises the opportunities for detecting slow changes in ecosystem function caused by gradual environmental change. Summaries are made widely available via the ECN web site and annual reports are made to DETR.

19. The work funded under BAGEC has had some effects upon impact predictions and it is likely that more data will emerge, particularly associated with differential responses between species and with soil-plant-atmosphere interactions. The potential problem is that outputs are "random" being based on new scientific information and thus there is no clean policy line between funding, research outputs and impact predictions.

20. Emissions of the "greenhouse gases" methane and nitrous oxide from livestock are thought to contribute to global warming and MAFF has funded a series of studies to produce a UK inventory of the total production of these gases from farmed livestock and to identify possible abatement measures. The work has resulted in a methodology for producing inventories of emissions which is technically in advance of IPCC methodology and more accurate. Results will be used by MAFF to develop policies and guidelines to reduce emissions from agriculture to meet national and international targets. The work highlights the need to model the overall effects (over a variety of scales) of any measures that may be recommended, before drawing up a policy; a systems approach is essential.

What Critical Appraisal there has been of Models Predicting Climate Change Increasing Concentrations of Carbon Dioxide, and other Potential Drivers

21. IACR has developed mathematical models for assessing agricultural risk due to climate variability and climate change. Studies on crop growth have covered both UK and Europe with funding from MAFF and EU. As a basis for this type of research, it is essential that the crop growth models used are thoroughly validated. IACR scientists have been heavily involved in international activities to test a range of models against datasets.

22. The only major international effort to test soil carbon models using data from long-term experiments was organised at IACR-Rothamsted.

23. IGER was involved in the development of refined climate change models which also involved Universities and the Met Office. IGER's MAFF contract was based on IPCC scenarios and Met Office models to predict climate change. However, new data is continually being produced which needs to be incorporated and is a driver for new models.

24. More integrative studies have been supported, eg by MAFF, which attempted to bridge the gap between mechanistic studies and the basic predictions that were part of the early IPCC models. Unfortunately, resources were limited confining investigators largely to the application of existing models. It is suggested that integrative modelling is still a major weakness.

25. DETR, for example, commissioned scenario and impact assessment studies which were quite influential and did represent a determined attempt to integrate across scales and between sectors.

26. All the necessary building blocks for a coordinated approach appear to be in place, from directed research through to policy scenario and impact analysis. But there have been problems, for example:

- insufficient discussion of uncertainty at any stage;
- insufficient integration of research provision into the analysis of impacts. This has been particularly true of "scale-up" modelling;
- impact analysis and the weighting for policy purposes of rare but catastrophic events. Most impact analysis applies the "trends in means" approach and this may not be the most relevant for climatic variables; and
- it was not always clear to those generating the data who was going to use it and how or why.

27. All models are subject to uncertainty and revision of global change scenarios will be a continuing feature of advice on climate change.

THE DEGREE OF GOVERNMENT AGREEMENT WITH SCIENTISTS IN RELEVANT SPECIALISTATIONS REGARDING ACCEPTED EXPLANATIONS OF CLIMATE CHANGE

28. IACR agrees with the IPCC analysis that the upward trend in the earth's temperature is, at least in part, driven by human-induced increases in greenhouse gas emissions. It is aware that there is some evidence to suggest that non-anthropogenic processes, such as changes in the energy output of the sun may also contribute to the observed global warming. However, it is fully in agreement with the IPCC view that the evidence for a human-induced contribution is compelling and that the consequences of climate change are so profound that it is essential that drivers that are influenced by human activity be tackled.

29. Other researchers are more cautious suggesting that there is considerable uncertainty about all but the most global projections on climate change impacts. Since individual groups of scientists have been asked to comment on specific functions, the overviews tend to be fragmentary. In addition, Government Departments tend to commission their own studies and it is unclear how much cross-fertilisation there is.

January 2000

APPENDIX 5

Memorandum submitted by the Climatic Research Unit, University of East Anglia, Norwich

INTRODUCTION/BACKGROUND

1. The Climatic Research Unit (CRU) has been in existence for 28 years. It receives funding from several sources (eg UK government departments, EU, US Department of Energy, UK Research Councils, Industry/Business and organizations with charitable status) and is partially supported by the University of East Anglia, through the School of Environmental Sciences. Over this time, it has built up an excellent reputation for work in the Climate Change field. It is most well-known for its studies on instrumental climate (jointly producing with the Hadley Centre of the Meteorological Office the time series of hemispheric/global temperatures used by IPCC), paleoclimate (past estimates of temperature for the last few millennia) and projections of future climate (again joint work with the Hadley Centre). CRU is the dissemination point for all climate model data from the Hadley Centre (funded by DETR, Department of Environment, Transport and the Regions, through the Climate Impacts Link project), adding value/details to future scenario integrations of Hadley Centre models. This includes validating the models against observational fields. As an academic institution, CRU does not have a position on this, or any other matter. The views expressed here are the synthesis of individual members who have worked in this area.

2. This memorandum will address the five specific questions, referring back as appropriate to the terms of reference.

Q1. *What other reasonable explanations, other than increasing concentrations of* CO_2 *in the atmosphere, are you aware of for the upward trend in earth temperatures? Has your organization conducted any assessment of these alternatives and if so, with what conclusions?*

3. First, CO_2 is not the only human-produced greenhouse gas. There are also CH_4, N_2O and CFCs, often referred to collectively as greenhouse gases. CO_2 alone is only about 60 per cent of the problem. Aerosol emissions (eg sulphates, soot, and some other particulates) are also considered as part of the problem. Aerosols have an inverse effect (ie should lead to cooling) but their use is being reduced on other pollution grounds (eg they are the root cause of acid rain). The question is taken, therefore, to refer to "Anthropogenic emissions or activities, which alter the radiative balance within the atmosphere", or the loose media phrase "global warming", ie not-natural.

4. There are only two possible natural factors that could potentially affect global scale temperature changes, on the annual-to-century timescales (ie similar to that of anthropogenic activities). These are variations in solar output and the effects of large explosive volcanic eruptions.

5. It has been shown that large explosive volcanic eruptions (particularly those in the tropics and subtropics, 30°N-30°S), over the past century, have caused short-term climate change. Mt Pinatubo in the Philippines, for example, erupted in June 1991, and caused a global average cooling during 1992 and 1993 (mainly from May to September, ie northern summers) of about 0.3°C (see, eg, Kelly *et al*, 1996). Larger eruptions in earlier centuries may have caused greater reductions in temperature. The number of volcanic events over the last 600 years is relatively few (-20 in total, see Briffa *et al*, 1998).

Impacts might become larger if volcanoes erupted together compounding effects, but there is no evidence of this happening, except in the late 17th century and the 1810s. The only significant eruptions this century occurred in 1902, 1912, 1963, 1982 and 1991.

6. Global temperatures also vary on timescales of three to five years as a result of changes in the tropical Pacific Ocean (El Niño/La Niña events). El Niño events cause warmer years globally and La Niña cooler ones.

Changes in the frequency/severity of these events have occurred over the last 150 years, but not to an extent to cause any change in global scale climate on decadal and longer timescales.

7. It is known that the Sun's output varies on many timescales, but we have only recently begun to realise exactly how by monitoring the Sun above the atmosphere using instrumentation on satellites. Ground based measures of solar output are available for several centuries but they are influenced by the atmosphere. Despite this, several estimates of past variations in solar output have been made which extend back several centuries. Variations in solar output have been considered as being important by scientists since the 18th century. The possibility that solar variability might account for all or part of the global warming trend has been examined by Kelly and Wigley (1990, 1992) in a series of studies that have assessed the relative contribution of solar forcing of climate, based on sunspot numbers and solar cycle length and anthropogenic activities. The overall conclusion of this work is that although there is evidence that solar variability may affect global temperature on these timescales, the effect is markedly less than that resulting from anthropogenic activities. In other words, these authors and all in CRU would conclude that anthropogenic activity is the most plausible explanation for the bulk of the observed warming trend.

Q2. *What critical appraisal of climate change models has your organisation performed and with what result?*

8. First, there is no such thing as a climate change model. Climate models solve the equations of physics (mass, energy, momentum) and the climate model run in the UK by the Hadley Centre is essentially the same computer code that produces each day's weather forecasts. The models are run in (control) present mode and then the models atmospheric composition is altered to produce a perturbed (scenario) integration. The change produced by the model is the difference between the perturbed and control integrations. We have extensively evaluated the performance of the control runs of General Circulation Models (GCMs) over at least the last 10 years in projects funded by DETR. The results of this work have obviously gone to DETR as annual and project reports and also as publications to the peer-review literature (see, eg, Hulme *et al*, 1993; Airey and Hulme, 1995, Osborn *et al*, 1999). The basic conclusions of these studies are:

- GCMs have improved over the last 10 years (as have weather forecasts);
- the Hadley Centre model is considered by most atmospheric scientists to be one of the best two in the world at the moment (the other is at the Max Planck Institute for Meteorology, Hamburg, Germany). The USA has diversified its effort into a number of centres and has fallen behind. If research there was more co-ordinated, it ought to improve; and
- the latest two Hadley Centre models (HadCM2 and HadCM3) do very well at simulating the climate over the UK and Europe, reproducing features and interrelationships between surface climate (temperature and precipitation patterns) and the circulation that occur in the real world (see references above).

Q3. *How much agreement is there between scientists internationally regarding explanations for climate change?*

9. The most comprehensive assessment of explanations for climate change are given in the reports of the Intergovernmental Panel on Climate Change (IPCC) in 1990 and 1995. Most of the world's leading scientists are involved in contributing to the reports and most would agree with the main conclusions. The large majority of atmospheric scientists would accept IPCC's most quoted conclusion that "The balance of evidence suggests a discernible human influence on global climate". There will be differences of opinion on some of the details but all atmospheric scientists would accept that IPCC provides the concensus view. IPCC and climate scientists both accept there are knowns and unknowns, with respect to the causes of climate change, but there are no great schisms within the community regarding what the important mechanisms are. This concensus has been there since CRU began in the 1970s and predates IPCC.

Q4. *To what extent are the fruits of your research fed into Government machinery and by what means? Do you think that the Government is made sufficiently aware of alternative explanations? By what means does this occur?*

10. The results of our research reach the government macinery in a number of ways: through direct contact with politicians (ministers and MPs), through contract reports to departments such as DETR (informing also our contract officers when important papers will appear in journals like *Nature* and *Science*), through collaboration with government scientists (eg the Hadley Centre of the Met. Office and NERC Research Institutes), through publications in the scientific literature, and through media. We also inform other departments, such as MAFF and DoH, and advise the UK Climate Impacts Programme (funded by DETR). Over the last few years we have occasionally been consulted by DETR concerning statements made by ministers in the House and elsewhere. In our view, the government is totally briefed on our research results regarding the causes of climate change, validation of GCMs, and observed changes in a global and UK climate. We always emphasise areas of uncertainty, although these are often missed by the media who like things to be black and white.

11. Our belief is that there are no credible alternative explanations (ie the 0.6°C increase in global temperatures during the 20th century cannot be explained without including a major component from anthropogenic emissions to the atmosphere). We hear, occasionally, of alternatives (all in the grey literature or on web pages). In the climate area, as in all science, credibility is measured by publication in an appropriate peer-review journal. As climatologists we intuitively rank journals, depending on our knowledge of how easy/difficult it is to get articles published (ie how rigorous the journal's reviewing policy is). CRU would rank the following journals; *Nature, Science, J. Climate, J. Geophysical Research, Climate Dynamics,* the *International Journal of Climatology* and *Geophysical Research Letters* in the premier league. We mention this, as any alternative explanations should appear in these sort of journals for them to have any credence. Anyone can publish a book or set up a web page to expound their views. This is not what we understand as scientific publication. If alternative explanations were published in these journals we would be the first to be informing departments like DETR.

Q5. *How important is the International (sic) Panel of Climate Change in co-ordinating research on climate change and disseminating findings (sic)?*

12. The IPCC does not co-ordinate research into climate change. Its role is to review existing research and to advise the international community on the current state of scientific and technical understanding. In this respect, IPCC makes authoritative statements but only based on material published in the peer-reviewed scientific literature. In this way it plays a crucial role in disseminating research findings by reaching a concensus judgement of all the published literature on the subject.

13. The IPCC does not fund any scientific research. In the UK, the Technical Support Unit for Working Group 1, funds scientists involved in writing drafts of chapters to attend co-ordination meetings, where the lead authors get together. The IPCC's recommendations regarding the current issues in climate (eg what we need to know more about to reduce uncertainties) does influence funding in indirect ways, but only alongside a host of other factors.

15 February 2000

References

These references are those specifically referred to in this memorandum. CRU has written several hundred scientific papers. Of the names on these papers, CA Senior and SFB Tett work at the Hadley Centre and FH Schweingruber at the Swiss National Institute of Forest, Snow and Landscape research. All others are or were members of CRU at the time the papers were published.

Airey, M and Hulme, M, 1995: Evaluating climate model simulations of precipitation: methods, problems and performance. *Prog Phys Geog* **19**, 427–448.

Briffa, KR, Jones, PD, Schweingruber, FH and Osborn, TJ, 1998: Influence of volcanic eruptions on Northern Hemisphere summer temperatures over 600 years. *Nature* **393**, 450–455.

Hulme, M, Briffa, KR, Jones, PD, and Senior, CA, 1993: Validation of GCM control simulations using indices of daily airflow types over the British Isles. *Climate Dynamics* **9**, 95–105.

Kelly, PM and Wigley, TML, 1990: The influence of solar forcing trends on global mean temperature since 1861. *Nature* **347**, 460–462.

Kelly, PM and Wigley, TML, 1992: Solar cycle length variations, greenhouse forcing and global climate. *Nature 360*, 328–330.

Kelly, PM, Pengqun, J and Jones P D, 1996: The spatial response of the climate system to explosive volcanic eruptions. *Int J Climatol* **16**, 537-550.

Osborn, TJ, Briffa, KR, Tett, SFB, Jones, PD and Trigo, RM, 1999: Evaluation of the North Atlantic Oscillation as simulated by a coupled climate model. *Climate Dynamics* **15**, 685–702.

APPENDIX 6

Memorandum submitted by the Institute of Biology

1. The Institute of Biology is the independent charitable body charged by Royal Charter to represent UK biologists and biology. With some 16,500 members and over 70 specialist Affiliated Societies, it is well placed to respond to the Select Committee's consultations on "Scientific Advice".

SUMMARY

2. The principal points of this response are:

(i) that climate change is a complex issue fraught with uncertainty (paragraph 5); there is also uncertainty over climate change impacts (paragraph 6); and uncertainties in the form of ecological surprises cannot be modelled (paragraphs 14 and 17);

(ii) that Governments and its Departments are unlikely to welcome such uncertainty in advice, even though being transparent over matters of certainty and accuracy is the best way to provide advice (paragraph 6);

(iii) that scientific advice can change as more questions are asked and detailed information is provided, by researchers (paragraph 8). More research is still required (paragraphs 7 and 9) as there are many unanswered questions;

(iv) that models are only approximations (paragraph 11) but these can be tested (paragraph 12). However, understanding how this is done for each model requires an understanding of mathematics (paragraphs 15 and 16);

(v) that some local government administrations appear less aware of scientific advice relating to climate change and this is likely to result in costs on society (paragraph 21).

GENERAL POINTS

As the results of scientific research have become available advice has changed from that of possible global cooling to a certainty of global warming

3. Notwithstanding that the Select Committee (rightly) takes it as given that the global temperature and carbon dioxide levels have both been increasing, it is of note that this subject is one where the views presented to Governments by the scientific community have changed considerably over the past three decades. In the 1970s, following the discovery that (warm) interglacials (such as the one we are in) last only a few thousand years, it was thought that the World may well be on the brink of another (cold) glacial. Indeed, there was concern that a glacial might be precipitated by the cooling effects of air pollution (sulphate aerosols and dust). In the 1980s, it became apparent that there were several competing (both warming and cooling) factors forcing the climate. The 1990 IPCC (Inter-Governmental Panel on Climate Change) report concluded that it was "certain" that "emissions resulting from human activities are substantially increasing the atmospheric concentration of greenhouse gases . . . [and that] these increases will enhance the [natural] greenhouse effect". Finally, the late 1990s have seen a greater confidence in the accuracy of global warming models, though regional climate projections may be invalidated due to "surprises" such as abrupt changes in sea circulation. In short, as the results of scientific research have become available advice has changed from that of possible global cooling to a certainty of global warming. (The uncertainties that remain currently centre on the exact nature of future global warming, its expression regionally over time, and its impact on living systems (see paragraphs 6 and 17)).

Global warming does not prevent the prospect of regional cooling

4. Part of the confusion between global warming and global cooling arises from the past failure to emphasise that the problem is one of "climate change". While overall warming is taking place, this does not prevent regional cooling. Certainly, rises in global temperature and carbon dioxide levels will result in higher average temperatures at ground level in some areas. In others, the switching off of the Gulf Stream (paragraph 20), for instance, or El Niño effects may result in marked regional cooling. Given that a number of species are at the edge of their range in the UK, it is fairly certain that these species will extend or contract their range with climate change. Therefore the supposition that any response experienced in the UK will necessarily be to warming alone is unfounded.

Climate change is complex, erratic on the small scale and has inherent uncertainties which impede comprehension

5. Temperature is not the only factor related to climate change. Rises in sea level pose other problems that will vary markedly from region to region. The difficulty of predicting storm and flood events will further emphasise the uncertainties and consequences of these changes. It has therefore been difficult for scientists to influence the thinking of the general public, and decision-makers, away from simple trends towards an understanding of this globally complex and, in terms of the smaller scale, erratic phenomena.

There is additional uncertainty with regards to the impacts arising from climate change—policy makers are unlikely to welcome this in advice

6. Not only is there uncertainty as to the way climate change will manifest itself, but also uncertainty as to climate change impacts. For instance, uncertainty in terms of climate change effects on ecosystems. Not only do species react differently to warming, but also the different relationships between species are also prone

to change with the climate. Consequently, the likely species composition (of even comparatively stable climax communities) following a period of climate change is not certain. Governments and its Departments are unlikely to welcome such uncertainty in advice, even though the scientific community is being transparent over matters of certainty and accuracy. This is the best way to provide advice.

Current research does not sufficiently focus on areas that could assist with climate change advice

7. It is also important to stress that research on changes in ecosystems in response to changes in their environment, and even on ecosystem function and composition in "normal" conditions, has been comparatively neglected by emphasis on research which is "market-led". Few Government Departments and their Agencies, and even fewer commercial companies have been prepared to invest in the long-term ecological research that is needed to understand ecosystem function. For instance, one example is that more research is needed on the way carbon is sequestered. Here, an even more specialist example is illustrative of the gaps in our knowledge. Lichens are common to systems covering some 8 per cent of the terrestrial surface, yet little detail is known as to their sequestration impacts even though it is known that they convert rock silicates into oxalates and that this in turn has an impact on the carbon cycle. Yet again, fungi (and other detritovores) play a key role in the carbon cycle, but the effects of climate change on fungal activity are still largely uncharted territory.

Scientific advice can change as more questions are asked and detailed information provided by researchers

8. In terms of advice to Governments, this will mean that historically the nature of much scientific advice on climate change has changed with time. This does not mean that earlier scientific advice is wrong, rather that the earlier advice was less complete and in want of more research. Indeed, the early (1970s) picture portrayed was correct in that interglacials are comparatively short compared to glacials, so that in "geological terms" it is likely that our mild interglacial climate will be replaced by that of a cooler glacial. It was also correct to say that there are factors that "force" the climate in a cooling way. However, the research had not then been undertaken to ascertain the strength of both the cooling and warming factors. Nor had the detailed research then been conducted (from which we benefit from today) using palaeobiotic and abiotic indicators of past climates. As questions are asked, and appropriate research undertaken, so a more detailed picture is assembled.

For meaningful scientific advice to be given to politicians, sufficient research needs to be done to address the numerous frames of reference politicians use

9. The history of climate change research illustrates that not only does additional research provide a more complete picture in terms of detail, it (a) uncovers exceptions to the rule, and (b) places information in context. If the exceptions to the rule are striking, or if the context is markedly different, then scientific advice may well "appear" to change. In the instance of climate change the 1970s picture of possible cooling was initially set against a context of palaeontological data that (correctly) showed that mild interglacials were comparatively short compared to cold glacials. However, when in the 1980s this was placed against the context of short-term (geologically speaking) of a few centuries of human-generated greenhouse gas warming factors, the picture changed. Neither picture is inaccurate. Both are accurate within their respective frames of reference. For meaningful scientific advice to be given to politicians, sufficient research needs to be done to address the various—often numerous—frames of reference that politicians use.

SPECIFIC POINTS

The specific questions asked by the Select Committee are in bold italic below.

(A) The way to which the Government has been advised of potential alternative explanations, how these alternatives have been assessed and what conclusions have been drawn.

We are unable to answer

10. We are unable to answer as we have no record of all the advice been given Government, nor privy to the way Government assessed the advice.

(B) What critical appraisal there has been of models predicting climate change, increasing concentrations of carbon dioxide and other potential drivers.

Models can only portray approximate elements of reality

11. Those models that are published in primary research journals are subject to peer review. It is recognised that models can only portray approximate elements of reality. They cannot in any way duplicate reality.

Models can and are tested

12. Models can be and are tested to see how closely they match reality. One fair (but not "good" or "perfect") test of a climate model's predictive ability is, instead of running the model forward into the future from the present, to run it backwards into the past. It can then be compared with reality's known past as opposed to an unknown future.

Models differ and have different utility and predictive ability

13. Some of the Hadley Centre's models for global climate compare well with reality. Models that attempt to show regional change are known to be far less reliable. Models differ and have different utility and predictive ability.

Models cannot account for all surprises but this does not make them completely useless

14. Models cannot account for all surprises. The future is likely to hold a number of surprises. These surprises are of varying likelihood. It would be a surprise if one in 10 Chinese had a car in 10 years time, but not impossible. This would have a climate impact. It would be far less likely, and hence a far greater surprise if a near Earth-asteroid impacted disrupting the global climate in the next 10 years. Neither of these would necessarily be included in a climatic model (unless deliberately programmed), but this does not make climate models completely useless.

The maths underpinning complex climate models is a simplification of reality

15. Much of the discussion of "models" is hopelessly unrealistic. The many factors and relationships involved in global climatic change are so complex that the only way of comprehending them is through the use of mathematics. Various mathematical formulations are employed to seek to understand and explain changes in natural systems by means of approximations to the underlying reality. While capable of incorporating much greater complexity than any verbal argument, mathematical formulations are also necessarily simplifications of reality.

Models have improved but communicating how they are constructed to the public remains difficult

16. Scientists today have greatly improved access to the statistical thinking that underlies the building, testing and use of mathematical models. There is, therefore, much greater confidence in the models that have been developed during the last decade or so. In particular, it is now possible to test the utility and predictive ability of models. What is more difficult is the communication to decision-makers and others the complexity that underlies these models and makes their use so essential. We still live in a society which arguably has not the general level of mathematical ability to appreciate properly mathematical models.

Beware of surprises, models have their limitations

17. However, we again emphasise the possibility of "ecological surprise" that will be beyond the scope of models (paragraph 6). This might occur as natural and man-made systems become increasingly subjected to changes in environmental influences that are outside our range of experience, at least in historically recorded time. Again, such "ecological surprise" is less likely to be damaging to the economics and welfare of human society if they can be quickly recognised and understood or, better still, anticipated. This will necessitate groups of scientists supported by Government and truly independent of all the commercial and political pressures now dominating the funding of scientific research. Such scientists need to be able to "think the unthinkable" and assess both the probability and the consequences of the "unthinkable" occurring. Models do have their limitations, and this is one way that such limitations can begin to be overcome.

Models differ, many are still coarse

18. It should be noted that models differ in their resolution and predictive capacity. It would appear that there can be increasing confidence in global temperature models; yet those that present regional effects are still fairly coarse. Models usually only reflect the key elements of a process and so the results are always subject to a margin of error or uncertainty.

(C) The degree of Government agreement with scientists in relevant specialisations regarding accepted explanations of climate change.

We are not privy to Government thought but perceive it to accept the IPCC view

19. Not being privy to Government thought we cannot answer this with great confidence. However our

perception is that UK Governments subsequent to the first IPCC report (in 1990) have accepted the IPCC view. We believe that the IPCC view, with its various caveats, is sound within the frames of reference allowed by research to date.

Conversely Government Departments may not be fully accepting IPCC caveats

20. However, we wonder whether Departments possibly view the regional consequences of global warming solely as one of a warmer climate for the UK. It may well be that global warming in disrupting the North Atlantic Broecker salt conveyer could shift the North Atlantic Drift (the Gulf Stream) (see paragraph 4). Without the warm currents around the European peninsular, UK winters could become as cold as those in Newfoundland, Canada. The IPCC has, as one of its caveats, warned of such "surprises", as we have done in referring to "ecological surprises" in the paragraphs above. There appears to be little discussion of IPCC caveats, though this might be because of the vagaries of the implications for policy[1].

Some local government administrations seem unaware of the scientific advice on climate change. These could result in costs

21. Locally, some Councils and local government administrations seem unaware of the scientific advice relating to climate change. This is likely to incur a cost on society. For instance, some home construction has taken place since the 1990 IPCC report on land whose defences from the sea have yet to be made secure in the long term.

POST forms a useful adjunct to scientific advice from the scientific community

22. We believe that Parliamentarians find that the Parliamentary Office of Science and Technology (POST) provides a useful service in providing straightforward profiles of scientific issues. We welcome the Parliamentary and Scientific Committee's work in establishing this office in 1989, and believe that POST forms a valuable adjunct to scientific advice from the scientific community.

16 February 2000

APPENDIX 7

Memorandum submitted by the Natural Environment Research Council (NERC)

INTRODUCTION

1. The Natural Environment Research Council (NERC) welcomes this opportunity to provide evidence into the Committee's enquiry into scientific advice on climate change.

2. NERC is the UK's leading organisation for basic, strategic and applied research and training across the spectrum of the environmental sciences. NERC's purpose is to support high quality scientific research, survey, monitoring and postgraduate training with the objective of enhancing knowledge, understanding and prediction of the environment and its resources. NERC achieves this through its support of scientists at universities and through its own Centres and Surveys: the British Antarctic Survey (BAS), the British Geological Survey (BGS), the Centre for Coastal and Marine Sciences (CCMS), the Centre for Ecology and Hydrology (CEH) and the Southampton Oceanography Centre (SOC—a joint venture with the University of Southampton).

3. NERC considers knowledge transfer, including provision of advice based on its scientific research, to be a key element of delivering its mission. Provision of scientific advice is governed by guidelines drawn up by the government's Chief Scientific Adviser. NERC is contributing to a current DTI consultation exercise with a view to updating these guidelines.

4. Our evidence, which includes comments from NERC's Centres, Surveys and University units, is structured around four main headings in order to cover the questions posed by the Committee.

---

[1] The original memorandum was received on 16 February 2000. The following additional information was received on 11 October 2000: While this point remains valid, the specific example we give (of the Broecker Salt Conveyor shutting down so preventing the North Atlantic Drift (Gulf Stream) from warming us in winter) no longer applies. Three months after the Institute submitted its evidence to the Committee, NERC announced it was to formulate a research programme on this very topic. The Institute sent a representative to the NERC programme's planning meeting.

Research and other activities funded by NERC in relation to climate change

5. In setting NERC's Science Budget allocation for the current planning period (1999–02), the government gave NERC three priorities one of which is "to develop a climate research agenda, including joint work with EPSRC (Engineering and Physical Sciences Research Council) and ESRC (Economic and Social Research Council)".

6. In December 1998 NERC set up a small *ad hoc* group chaired by Professor Brian Hoskins FRS (Reading University) to examine the coherence of NERC's climate change research portfolio, particularly with regard to future UK climate change research needs and in the context of research supported by other Research Councils. The group concluded that: NERC had a coherent suite of climate change programmes (examples summarised at Annex 1); linkages with EPSRC would need to be formed in the area of marine renewable energy, possibly through the Climate Change Centre (see paragraph 7); and there was more research required in land-vegetation-atmospheric modelling. The group endorsed the links with Government Departments and the links between NERC's modelling of the climate system and the work of the Hadley Centre.

7. NERC, together with EPSRC and ESRC is establishing a new interdisciplinary Climate Change Centre. Up to £10 million will be available over five years for the Centre to conduct innovative research, integrated across environmental, technological, and socio-economic disciplines. Collaboration with other groups in the UK and abroad will be important. Through integrated research, the Centre aims to help society find sustainable solutions to the problems posed by climate change. Solutions will involve mitigating against climate change, as well as adapting to its inevitable impacts. The Centre will be required to utilise and create effective mechanisms for turning relevant research results into scientific advice to government and business. The DTI has pledged a further £70K per annum to support the centre's business liaison activities.

Assessments of the validity or otherwise of climate models

8. A senior SOC scientist has been advising climate modellers from the USA, UK, Germany and elsewhere on the ocean model requirement for good reliable climate predictions, including the need for higher resolution models to avoid over emphasis of the chances of catastrophic climate change around the North Atlantic.

9. NERC is funding a new thematic programme PRESCIENT (Palaeoclimate Research and Earth System Modelling for Enhanced Climatic and Environmental Prediction). The programme will provide high quality, high resolution palaeoenvironmental data to enable rigorous testing of the capabilities and reliability of General Circulation Models (GCMs). A specific focus will be on increasing the sophistication and versatility of the Hadley Centre's Earth System model. This will improve our ability to disentangle natural and anthropogenic climate change and allow greater confidence in the detection and attribution of human-induced climate change through a better understanding of natural climate variability.

Investigation into the possible alternative explanations for apparent trends in climate change other than increasing concentrations of CO_2

10. In 1995 the Inter-governmental Panel on Climate Change (IPCC) concluded, "the balance of evidence suggests a discernible human influence on global climate". However at the present time we cannot be sure of the extent of this influence. Not enough is known about positive and negative feedback to model climate change as a function of atmospheric change. Therefore current natural changes cannot be fully separated from anthropogenic change.

11. Science may still not have identified all the potential contributors to global climate change. Recent research at the Rutherford-Appleton Laboratory has shown how measures of geomagnetic activity can be used as a monitor of changes in solar irradiance. Using records from a UK magnetic observatory extending over 130 years UK researchers have found that increases in solar output over that time could be sufficient to account for at least some of the observed rise in global temperature over the last 30 years.

12. NERC is in discussion with the Particle Physics and Astronomy Research Council (PPARC) concerning a possible joint research programme to investigate solar variability and its role in climate change.

13. To understand the possible significance of alternative explanations, more attention should be given to the modelling and prediction of climate changes that occurred naturally either side of the last ice age. Historical data can be an invaluable resource. TIGGER (Geological Aspects of Terrestrial Initiative in Global Environmental Research) a NERC programme which has now finished, considered a series of proxy data for the past climate change. This provided valuable insights into our knowledge of climatic and ecological change over the past millennia. Similar insights are possible through RGGE (Rapid Global Geological Events) and the now closed NEAPACC (North East Atlantic Palaeoceanography and Climate Change) NERC thematic programmes. The geological record could be used to a greater extent in the calibration of climate change models.

14. The global carbon budget remains one of the major uncertainties in the earth system. As part of the International Geosphere Biosphere Programme (IGBP) CCMS have been carrying out research for the Joint Global Ocean Flux Study (JGOFS) into sequestration of carbon from the atmosphere. The project includes experiments designed to increase ocean carbon sequestration by the addition of iron to the system.

15. Methane and methane hydrates could also play an important role in the future. The Ocean Drilling Programme (ODP), an international research effort aimed at scientific investigations beneath the seabed, has discovered that there are huge masses of methane producing bacteria living within the sediments beneath the Earth's ocean basins. The methane, generated by these bacteria can escape by percolating through the seabed, into the oceans and then into the atmosphere. It could be a significant component of the greenhouse gas equation.

16. The rate of escape of this gas is moderated by the extent of the methane hydrate cap, within the deep continental margin sediments. Methane hydrate is a compound of methane and water that forms an ice-like substance under conditions of high pressure and low temperature. More methane could exist as methane hydrate than all the known reserves of natural gas, worldwide. This makes methane hydrate a vast potential source of energy, but also a huge natural driving force in global climate variability. Under the relatively stable conditions the temperature of the deep ocean keeps the methane hydrate cap relatively stable. However any warming could destabilise the hydrate cap and release huge pulses of methane into the atmosphere. Further research is needed to determine the global extent of methane generating bacteria, methane hydrates and the temperature variability of deep oceanic bottom waters, along continental margins.

Scientific advice on climate change based on NERC research and uptake by Government

17. In 1997 Sir Robert May FRS, the Chief Scientific Adviser published a note on his own personal view on climate change. He also made the following comments about climate change research in the UK "Ultimately the problem of climate change demands international co-operation and co-ordination. The quality of the UK's contribution to research on climate change is strong and out of all proportion to our relative size. We should aim to maintain this strength, so as to have international policy underpinned by fundamental understanding, to maintain our position of international and scientific leadership in this area, and to help persuade the world's sceptics that climate change is a real and serious problem". These comments emphasise the importance of the research that is carried by NERC and other bodies in the UK.

18. NERC research underpins scientific advice to government through a variety of direct and indirect routes, with key examples given in the following paragraphs. Concordats between NERC and key government departments and agencies (including DETR, MAFF and Environment Agency) provide formal communication channels to help ensure that NERC gets its message across effectively. NERC science has been used in other ways including:

- NERC contributed to the ACBE study *Climate Change: A Strategic Issue for Business* published in March 1998.
- NERC has made many and various inputs to the three assessments of the Inter-Governmental Panel on Climate Change (IPCC), both through staff as scientific experts and through its programmes, for example the International Permanent Mean Sea Level (PSMSL) recorded and held by CCMS.
- NERC collaborates with the Hadley Centre for Climate Prediction and Research for access to General Circulation Models (GCMs). Only through GCMs can process studies and case studies be used to benefit the understanding of the entire Earth System. Government, through DETR, benefits directly from this research.
- DETR has commissioned a report, involving the participation of NERC scientists, to study the risk of a collapse of the West Antarctic Ice Sheet and the consequences for the future of sea level.
- A briefing note was produced by NERC during the run up to the 1997 Kyoto Conference (copy attached). This took the approach of outlining the scientific certainties and uncertainties of the facts and consequences of climate change.
- A senior scientist at SOC has been an advisor for about 10 years, to a World Meteorological Organisation committee on the science of climate change prediction.
- Scientists from CEH have provided, under contract to DETR, independent estimates of the UK emissions of nitrous oxide and methane.
- Antarctic observations carried out over a 38 year period have revealed a systematic contraction of the neutral (unionised) atmosphere. This change is consistent with cooling induced by greenhouse gas concentrations and provides further evidence for the reality of anthropogenic climate change.

19. In general, Government departments are in a better position to comment on the value of advice based on NERC research and the extent of its uptake in the development of policy. However, NERC can point to a number of specific areas where the government has clearly acted on scientific advice resulting from NEC climate change programmes:

- Data extending over a 30 year period collected by BAS established the existence of ozone loss in the springtime Antarctic stratosphere. The time series now extends to 45 years, and the last 15 years have seen a further halving of ozone concentrations and the stratospheric cooling now extending into the summer. There is no doubt that the discovery of the ozone hole by BAS scientists spurred international action to eliminate CFCs.

- DETR has a contract with CEH to provide annual estimates of the UK inventory of carbon sources and sinks involving plants and soil. The methods and results form part of the UK report submitted under the United Nations Framework Convention on Climate Change (UNFCCC) and are used by DETR in discussions within the Subsidiary Body for Scientific and Technological Advice.
- Under contract, CEH provides DETR with assessments of the impacts on global ecosystems of future climates predicted by the Hadley Centre.
- The first set of Indicators of Climate Change in the UK that provided evidence that change is occurring were defined by a team from CEH, under contract to DETR. The report and the website were launched by the Minister for the Environment in 1999.
- Work by CCMS for MAFF has been used as a basis to plan coastal defence measures.

February 2000

Annex 1

NERC undertakes or funds a wide range of programmes which contribute to understanding of climate change. These include studies of past and natural climate change; processes, modelling and prediction of anthropogenic climate change; and impacts.

EXAMPLES OF NERC CLIMATE CHANGE PROGRAMMES

Palaeoclimate research and earth system modelling for enhanced climatic and environmental prediction.

Coupled ocean-atmosphere processes and their effects on European climate.

Clouds, water vapour and climate.

Arctic ice environmental variability.

Data assimilation and the interpretation of satellite data to understand variability and change in the atmosphere.

Geostationary earth radiation budget instrument.

Ocean circulation and climate advance modelling project.

Rapid global geological events.

Ocean drilling program.

Atmospheric chemistry studies in the oceanic environment.

Terrestrial initiative in global environmental research.

UK universities global atmospheric modelling programme.

Centre for Global Atmospheric Modelling.

Core strategic measurements for atmospheric science.

Ecosystems and environmental change.

Oceans, climate change and consequences for the coastal zone.

Large-scale long-term ocean circulation.

Climate Change Centre.

APPENDIX 8

Memorandum submitted by The Met Office

EXECUTIVE SUMMARY

1. The Met Office's Hadley Centre for Climate Prediction and Research carries out a broad programme of work into understanding the processes which control climate; representing them in a climate model; using this to simulate changes over the past 100 years and forecast changes over the next 100 years; monitoring recent trends in climate and attributing these to specific causes.

2. The evidence is compelling that (a) there has been a rise in CO_2 of about one-third since pre-industrial times due to human activities and that (b) there has been a rise of about 0.6°C in global mean temperature over the period of instrumental measurements since 1860.

3. Considerable research has been carried out by The Met Office's Hadley Centre to identify the relative contributing factors causing this rise in temperature. This involves a full analysis of all the known physical

mechanisms as well as the development and use of a state-of-the-art global climate model to simulate the climate record. The conclusions are:

- climate change since 1860 is greater than that due to natural climate variability alone and cannot be reproduced from purely natural factors such as volcanoes and solar activity;
- most climate change since 1945 has been due to human activities; and
- solar variability and lack of volcanic activity can partly explain the higher temperatures in the 1940s and 1950s.

4. Global climate models are the most scientifically comprehensive tools available for analysing climate and predicting change. The climate model developed and used by The Met Office's Hadley Centre is recognised as being world-leading, and has been comprehensively and successfully evaluated by examining its ability to:

- maintain a stable realistic climate over a 1,000 year timescale;
- reproduce the temperature trends over the last 150 years;
- give realistic representations of natural climate variability such as El Niño;
- be used with success in an essentially similar form as a weather forecasting model; and represent different palaeoclimate epochs.

5. Our findings and predictions are widely recognised, accepted, and used by Government and policymaking, especially those at Department of the Environment, Transport and the Regions (DETR) who have the policy lead in Government. Continued government funding of The Met Office's research, largely through DETR, is strong evidence of the value Government attributes to our work. Therefore we have good reason to believe that our advice has been influential on Government policy on climate change. Government also contributes to, and uses the findings of, the authoritative assessments of the Intergovernmental Panel on Climate Change (IPCC), which represent a consensus of international scientific opinion. The Met Office's Hadley Centre is a major contributor to IPCC assessments.

1. *Organisational details*

1.1 The Met Office is a government agency, operating as a trading fund, whose responsibilities include research into climate change, carried out by its Hadley Centre for Climate Prediction and Research. The Centre was established in 1990 and was built on a 20 year history of climate change research in The Met Office. The work is funded under contracts from the Department of the Environment, Transport and the Regions (DETR) (about £8 million per annum), the Ministry of Defence (MoD) (about £3 million per annum) and the European Commission (about £0.3 million per annum). This annual income of £11m supports some 100 people in the Hadley Centre, many of whom are recognised world experts in various aspects of meteorology and climatology, as well as the essential supercomputing facility which runs the climate models. The atmosphere and ocean modelling activities which comprise the climate models are developed in complementary research programmes which themselves support the other Met Office functions in weather forecasting and oceanography. These research programmes amount to a further £8 million per annum, and are funded by The Met Office's core customers. Thus The Met Office is able to maintain a larger research programme than either climate research or weather forecasting could maintain on its own, giving the UK a capability which is unique across the world. It is this synergy which helps ensure the Hadley Centre's world–class excellence.

1.2 The Committee has asked specifically for an indication of the research which The Met Office conducts in relation to climate change. There is a broad programme of work at the Hadley Centre, which can be summarised under the following headings.

- To understand processes in the atmosphere, ocean, cryosphere and on land which control climate and its change.
- To develop a climate model which represents these processes with increasing realism.
- To use the climate model to simulate recent change and variability, and to predict change over the next 100 years.
- To monitor global and national climate trends, using observations from land, sea, air and space.
- To combine observations and model simulations in order to attribute recent climate change to specific causes.
- Based on the above activities, to provide Government with the research results, advice and analysis it needs to inform policy.
- To communicate results more generally to a range of stakeholders, including government, media, industry, pressure groups and IPCC.
- To take advantage of underpinning research carried out in the UK, especially that at NERC institutes, and elsewhere.

1.3 Since its inception in 1990 the Hadley Centre has achieved a number of important advances, and some of these are listed in Annex A. The Hadley Centre predictions of climate change and other relevant assessments are regularly communicated to DETR officials and ministers, and to other government departments. Therefore, we believe we can be categorised as a "key organisation" as defined by the Guidance Note on Submitting Evidence, and therefore we are providing substantial evidence.

2 *Objectives of this Memorandum*

2.1 This memorandum aims to address the three issues raised by the inquiry under the following sections:

A. The factors which can cause climate to change, how these have been systematically explored as possible contributory factors to the upward trend in global temperatures, and the current best assessment of the specific causes.

B. How the models used to predict future concentrations of carbon dioxide and of climate change have been validated.

C. How Government has been advised of the above, and the extent to which it has accepted this advice.

2.2 The other specific questions posed to The Met Office by the Committee, on the validity of climate change models, the scrutiny of possible alternative explanations for apparent trends in climate other than increasing CO_2, and the dissemination of our output to Government, are also dealt with comprehensively in this memorandum.

2.3 Much of the background discussion on the greenhouse effect, greenhouses gases, climate modelling, observations, predictions and detection is only given in brief. A more detailed coverage can be found in the recent booklet "The greenhouse effect and climate change: a briefing from the Hadley Centre" available from The Met Office. Specific results are drawn from the work of the Hadley Centre and include research being carried out worldwide as appropriate.

SECTION A: UPWARD TREND IN THE EARTH'S TEMPERATURE AND ITS CAUSES

3. *Observations of climate change*

3.1 Figure 1 shows the change in global-mean, annual-average, near-surface air temperature (generally simply referred to as surface temperature) from 1860, when the first reliable global data is available, to 1999. The long term trend (solid line) shows a relatively stable period in the last half of the last century, a rise from about 1920 to 1940, followed by another period of little change to the mid 1970s. From then to the present day temperature has risen more rapidly, such that 1998 was the warmest year, and the 1990s easily the warmest decade, on record. Overall there has been a rise of about of 0.6°C in the period of instrumental measurements. Superimposed on this long term trend can be seen substantial natural year to year and decade-to-decade variability. We have considerable confidence in the temperature record; it has been carefully compiled and quality controlled by The Met Office in collaboration with the University of East Anglia, and three independent records (air temperature over land, air temperature over sea, and the temperature just below the sea-surface) show similar trends. Temperature rises have generally been greater at higher latitudes and over land areas.

3.2 Over the last 40 years the troposphere (the lowest 10-15km of the atmosphere) has warmed, and above this stratosphere has cooled. Instruments on satellites can remotely sense the temperature of the atmosphere, and there has been some well publicised disagreement about the extent to which they also show a warming. Recent work at the Hadley Centre has shown good agreement between satellite and in-situ (weather balloon) measurements in the atmosphere at a height of three–five km for the period where they overlap (1979 to the present). Figure 2 confirms that the trend of temperatures in the atmosphere over the last 35 years is similar to that at the surface, but also shows differences on a shorter timescale which are still a subject of investigation.

4. *Potential explanations of the trend and how these have been assessed*

4.1 There are several factors which could contribute to recent climate change; these will be briefly described and examined as possible causes of observed climate change over the century.

4.2 On a timescale of tens and hundreds of thousands of years, changes in the *earth's orbit* around the sun have led to a succession of ice ages and interglacials (the Milancovic theory). The earth emerged from the last ice age about 10,000 years before present (y BP), temperatures peaked about 6 000y BP and have very slowly declined since then. Except for some isolated events for which the reasons are understood, these changes are too slow to be significant in the context of the last 100 years and the next 100 years. Although the earth is likely to enter another ice age, this is unlikely to be for several thousand years.

4.3 On timescales of years to decades, the climate changes due to natural interactions between various components of the climate system (eg oceans and atmosphere). This is usually known as *internal variability,* as it is not driven by a factor external to the climate system. To examine this as the cause of recent change, we ideally require many hundreds or thousands of years of climate data, to see if there are periods in the past where climate has changed at the same rate as it has over the last century. Because, of course, such data have not been collected, we have to resort to either (a) a simulation of natural climate variability by a climate model or, (b) proxy temperature data, deduced from tree rings, etc.

4.4 The observed rise in temperature since 1860 is about twice as great as its variability simulated by a 1000–year experiment with the climate model, when all climate drivers are held constant. Thus, if the model simulation of natural internal variability is realistic, then the temperature rise over the last 100 years cannot be explained by internal climate variability.

4.5 Figure 3 shows average Northern Hemisphere (NH) temperature since AD1000 constructed by the University of Massachusetts from analysis of tree rings, ice cores, lake sediments, corals, etc. Although there are large uncertainties, the figure shows the degree of natural variability (which in this case includes internal variability and also the effect of solar changes and volcanoes) and indicates a sharp increase over the last 100 years. Again, if the proxy data are accurate, the recent rise is outside the bounds of natural variability. Both this and the model simulation described in the paragraph above indicate the detection of climate change, but cannot attribute it to a specific cause.

4.6 Two natural factors, volcanic "dust" and solar energy, can influence climate. Sulphur dioxide gas emitted by volcanoes will, if energetic enough, reach the stratosphere and form small sulphate particles, often known as volcanic dust, which can persist for a few years. This will reflect sunlight away from the earth and hence temperatures. The amount of volcanic dust in the stratosphere has varied considerably; from about 1880 to 1920 there were a number of energetic volcanoes which gave a high dust index; the period to about 1960 was cleaner, but since then a succession of volcanoes has kept dust index high for considerable periods. This volcanic dust variability can produce significant changes in global temperatures.

4.7 The earth's surface is warm due to the amount of solar energy (sunlight) falling on it; this is balanced by outgoing invisible infra–red energy emitted by the earth and atmosphere. If the sun's energy increases, the additional heat received will raise the temperature of the earth. Reconstructions of solar energy output show that it has varied over the last few hundred years. Simple calculations based on change in the amount of energy falling on the earth show that this would have produced a temperature change of only some 0.1 to 0.2°C over the last century.

4.8 To see if these two natural factors, solar output and volcanic dust, can explain recent climate change, we have driven the Hadley Centre climate model (described in Section B, paragraph 5) with changes in both. We find that the temperature change simulated by the model does not agree with that observed (Figure 4), and in particular does not give the steep rise over the last two decades. The two factors together do, however, lead to a relatively warm period in the 1940s and 1950s, when volcanic activity was low but solar activity was high.

4.9 There have also been suggestions that solar changes can affect climate via a secondary mechanism. The two main theories here concern the modulation of the ozone layer, and the modulation of cosmic rays and clouds. The latter theory points out that increases in the sun's activity will reduce the flux of cosmic rays striking the earth. It then postulates that cosmic rays have the ability to enhance cloud formation, and hence a reduction in cosmic rays will reduce the coverage of clouds. This will allow more solar radiation to reach the earth's surface and hence warm climate. Theories of the indirect effect on climate of solar activity have been investigated in a report prepared by the University of Reading under contract to The Met Office, at DETR's request, a copy of which is at Attachment A.[2] They conclude that solar induced changes in ozone could potentially amplify direct solar forcing, but published studies disagree on this. Regarding the cosmic ray/cloudiness theory, they find that:

- the variation in cloudiness is apparent, but is not systematic, does not exist in all data sets and may be influenced by El Niños or volcanic eruptions.
- there is a low confidence that a significant observational link exists between cosmic rays and clouds, but this possibility cannot be excluded.
- although there is a possible mechanism linking cosmic rays and clouds, there is no evidence that it occurs in the atmosphere, as definitive experiments are lacking.
- any link is more likely to be via high clouds, and to have caused a cooling over the past century, rather than contributing to a warming.

4.10 The climate of the earth is strongly influenced by the greenhouse effect. Certain gases in the atmosphere absorb some of the infra-red energy emitted by the earth and reradiate it. The net result of this is to trap some of the heat which would otherwise escape to outer space, and hence to warm the earth's surface and lower atmosphere. The greenhouse effect due to natural greenhouse gases, mainly water vapour and carbon dioxide, keeps the earth about 33°C warmer than it would otherwise be. Increases in the concentration of greenhouse gases due to human activities, such as the emission of carbon dioxide from fossil fuel combustion, and the release of new greenhouse gases, such as chlorofluorocarbons, will augment the natural greenhouse effect. The rise in concentrations of the major greenhouse gases (carbon dioxide, methane, nitrous oxide, CFCs, ozone in the lower atmosphere) due to human activities has been observed using instruments and the analysis of gases from ice core air bubbles and these were included in the climate model. Temperatures simulated by the model rise throughout the period, and match those observed up to about the 1960s, after which they grow much more quickly than observed, to become about 0.3°C too high by the end of the 20th century.

---

[2] Not printed.

4.11 Ozone occurs naturally in the stratosphere and its concentration has been decreasing over the last few decades due to chemical reactions with chlorine compounds formed from CFCs. This will have had the effect of a slight cooling of climate.

4.12 Human activities also lead to amounts of small particles (aerosol) in the lower atmosphere which (as with volcanic dust in the stratosphere) reflect back sunlight and directly cool climate. The most significant example is sulphur from the burning of fossil fuels, which oxidises to sulphate particles. This direct cooling effect is augmented by an indirect effect arising from the ability of aerosol to increase the reflectivity of clouds. The increase in sulphate aerosols has been added to those in greenhouse gases to explore the climate impact of all man-made emissions; whereas the observed rising temperature trend since 1970 is well simulated, the warmth of the 1940s to 1960s is not.

4.13 Finally, the model was driven with observed or reconstructed changes in all natural and all man-made factors. Figure 5 shows that this simulates a global temperature trend which includes within its range of uncertainty (blue shading) the observational record (red line).

4.14 The discussion above demonstrates how the global temperature rise can be explained only when both natural and human factors are taken into account. However, this agreement could be the fortuitous result of the cancellation of factors, for example if man–made climate change has been overestimated but is partly offset by internal climate variability. As a more rigorous test, we have also used comparisons between simulated and observed patterns of climate change, both the geographical distribution across the earth's surface and through the depth of the atmosphere. We have shown that observed changes from 1963–95 in atmospheric temperature patterns can be most closely simulated by the climate model only when human-made changes in greenhouse gases, sulphate aerosol and stratospheric ozone are taken into account. More recent work (Reference 9), based on the evolution of changes in the geographical distribution of surface temperature by season, indicates that human activities are largely responsible for changes since 1945. This technique discriminates against natural variability, volcanic and solar as possible causes.

4.15 From the evidence above, it can be seen that Hadley Centre scientists have applied substantial scrutiny to the question of what has caused recent climate change, to the extent that we can reasonably claim to be leading research in this area. Other institutes also play important roles, and we have excellent links with many of them, particularly Rutherford Appleton Laboratory, Scripps Institute of Oceanography (California), Massachusetts Institute of Technology, Max Planck Institut (Hamburg) and the Programme for Climate Model Diagnosis and Intercomparison in California. A workshop of selected leading international experts in this topic was organised by the Hadley Centre in 1997, supported by DETR and the European Commission. Senior staff at the Hadley Centre have been chosen as lead authors of the two IPCC chapters on "Monitoring climate change" and "Detection of climate change and attribution of causes" reflecting the status of the Hadley Centre in these key areas.

5. *Conclusions drawn on the cause of recent climate change*

The work described above leads to the following conclusions, which represent our best estimate of the causes of recent climate change:

- Climate change observed since 1860 is greater than that due to natural variability.
- Natural factors (volcanoes and solar activity) cannot reproduce the observed trend over the last 100 years.
- Emissions from human activity alone cannot explain all of the observational record.
- The inclusion of both natural and man–made causes can give a satisfactory agreement with observations.
- The use of statistical techniques to compare observations of patterns of climate change with those simulated by the climate model, allows us to judge that most of the climate change since 1945 has been due to human activities.
- Solar variability and lack of volcanic activity may explain the relative warmth of the 1940s and 1950s.

SECTION B: EVALUATION OF MODELS OF CO_2 AND CLIMATE CHANGE

6. *Critical appraisal of climate models*

6.1 To predict climate change we need to estimate:

- what the emissions of greenhouse gases (and other pollutants) will be in the future;
- what proportion of these emissions will remain in the atmosphere as increased concentrations;
- how the additional heating due to this will change climate.

6.2 For future emissions, we use scenarios derived by the Intergovernmental Panel on Climate Change (IPCC), each based on a range of future projections of socio-economic factors such as population, economic growth, energy generation and use, etc. We do not have the expertise to comment on the extent to which any or all of these scenarios is likely to correspond to real future emissions, but we note that the most recent IPCC "B2" scenario does at least give rise to CO_2 concentration increases which are close to those observed over the recent past.

6.3 Based on these emissions, future concentrations of CO_2 are calculated by IPCC using a model from the University of Bern. The ocean component of the model has been tuned to the measured progressive uptake of nuclear bomb radiocarbon, and validated using ocean measurements of CFCs.

6.4 Concentrations of other greenhouse gases (eg methane, ozone) are derived from Hadley Centre models of chemical reactions in the atmosphere, given projections of future emissions. The atmospheric chemistry models are assessed by comparison with observations from surface sites, ozonesondes and aircraft; model-simulated ozone profiles appear to be generally similar to those observed. Similarly, concentrations of sulphate aerosol from both human-made and natural sulphur emissions, are generated by the Hadley Centre sulphur cycle model. This is assessed by intercomparison with other climate models, and by comparison with measured values in the atmosphere. Both these show that the simulated concentrations of sulphur aerosols are substantially less than those observed or those from other models; development work is underway to improve this.

6.5 To predict climate change resulting from increases in greenhouse gas concentrations and changes in aerosol, we construct a mathematical model, based largely on the established laws of classical physics, which represents processes within and between components of the earth's climate system: the atmosphere, the oceans, the land and the cryosphere (snow and ice). That developed at The Met Office's Hadley Centre, arguably the most advanced available today, divides the climate system into a grid, 2.5° latitude by 3.75° longitude in the atmosphere and 1.25° by 1.25° in the oceans, with 19 levels in the atmosphere, 20 levels in the ocean and 5 levels in the land. All told, there are some one million grid points, at which equations describing the climate system are solved every half hour for a model experiment lasting typically 250 years.

6.6 The development of the Hadley Centre climate model benefits substantially from other research in The Met Office's programme. The climate model is a variant of the weather prediction model, and hence incorporates any improvements to the latter. This is particularly true of the atmospheric processes represented in the model: the global circulation of the atmosphere, convection, the boundary layer, clouds, etc. Many of these representations are generated from specific observations carried out by The Met Office's C-130 research aircraft. Similarly, the ocean and sea-ice components benefit from advances in The Met Office's operational ocean model developed for the Royal Navy.

6.7 The Hadley Centre climate model also incorporates representation of many processes in the atmosphere, oceans and land derived from research carried out worldwide but in particular by other UK institutes, particularly those of the Natural Environment Research Council (NERC). The description of vegetation and the terrestrial carbon cycle, for example, has been developed in conjunction with the Institute of Hydrology, and that in the oceans with the Southampton Oceanography Centre. The Hadley Centre climate model is now used by the NERC Universities Global Atmospheric Modelling Project, and their research feeds into the development of the model. Hence the advice to Government on climate change, based as it is on results from the Hadley Centre climate model, benefits from the underpinning NERC research.

6.8 The model has been improved, both in terms of the range of the processes incorporated and the accuracy with which they are represented. The basic mechanism by which increased greenhouse gases alter climate is well understood, and we can make a good estimate of the temperature rise which would follow a given increase in atmospheric CO_2, for example. But the consequences of an initial warming can act to produce a substantial feedback, either to enhance or reduce it. For example, as the atmosphere warms it can contain more water vapour, which is itself a powerful greenhouse gas, and this multiplies the original warming. Because of these connections between different parts of the climate system, we need a model which incorporates them all interactively.

6.9 Currently, the operational climate prediction model (known as HadCM3) includes atmosphere, land, oceans, cryosphere, and the generation and climate impact of sulphate aerosols from SO_2 emissions. It does not yet include the natural carbon cycle, although a development model which does incorporate it has recently been used to produce the first climate prediction taking into account carbon feedbacks. It shows a substantially larger rate of climate change, due mainly to increased respiration of CO_2 from soils as the climate warms.

6.10 Following optimisation of the physical processes in the model, it is run for many centuries given only the amount of energy received from the sun. It settles down to a climate close to that of the real earth and (unlike earlier models) it maintains a stable climate without the need to impose artificial transfers of heat and water between the atmosphere and ocean. This ability to simulate current climate increases our confidence in the realism of its predictions for the future.

6.11 The predictions of climate change which are made by the most recent Hadley Centre model are shown in Figure 6, based on the IPCC "B2" scenario of emissions. Global-average temperature rise is estimated to be about 2.3°C higher than today's by 2100. The rate of rise will be twice as great over land as over sea, and larger at high latitudes than at the equator.

6.12 Before using the model to simulate and predict climate, we test its realism in a number of ways. Firstly it has to give a reasonably realistic representation of some types of natural climate variability, such as the El Niño/La Niña, the monsoon and the North Atlantic Oscillation, and the overall internal variability of climate. Secondly, we examine the internal operation of the climate system, for example the way in which heat is transported around the oceans, by comparing model simulations with measurements. Thirdly we require it to give an adequate simulation of change over the last 50-100 years when driven by known changes in greenhouse gases, etc. Fourthly, it should be able to represent different climates in the past (palaeoclimates), particularly the warmth of 6,000 years ago and the Last Glacial Maximum 21,000 years ago. Fifth, a variant of the model is used for weather forecasting, providing a different, but nonetheless demanding, test.

6.13 These comparisons have been carried out and the results have been published (or submitted for publication) in the peer-reviewed literature; a list of publications and reports is given in Annex C.[3] The model does not give perfect representations of climate and its variability, and we make an informed judgement based on the degree of agreement about its suitability for use in predicting change in the future.

6.14 Climate models from a number of research centres are routinely intercompared under a World Meteorological Organisation programme. Results from the most recent intercomparison, which involved the previous generation model, showed that the Hadley Centre model gave the smallest overall errors of any model when compared to observed climatology.

6.15 Much of the uncertainty in climate change predictions comes from the poor understanding of the processes which give rise to feedbacks referred to earlier. The strength of some of these, such as that associated with water vapour, have been validated using present-day climate variability as a surrogate for climate change. This is not consistent with the view of Lindzen that amplification from water vapour feedback in the real world is much less than that in climate models, and this disagreement is currently being explored using a version of the model with very high vertical resolution, to see if the processes which Lindzen suggests are important.

6.16 The predictions of change which we do make are accompanied by estimates of uncertainty, based on the imperfect behaviour of the model (particularly the feedbacks between different parts of the climate system). Typically, the 2.3°C rise in global temperature predicted from the present day to 2100 is given an uncertainty ranging from about 1.3°C to 3.5°C. These values are calculated from the span of predictions from a number of climate models, although it should be stressed that the range is not a statistically rigorous one; for example, it does not correspond to one or two standard deviations. Work is underway at the Hadley Centre to "calibrate" the climate model using observations over the last 100 years, and use this to derive a better, statistically-based, estimate of future change and its uncertainty. The first paper on this technique has recently been submitted to *Nature*.

6.17 Recent discussions have focused on the likelihood of rapid climate change, due, for example, to changes in ocean circulation. The model predicts that, for man-made greenhouse gas emissions many times those projected, the ocean thermohaline circulation will decrease but will not collapse.

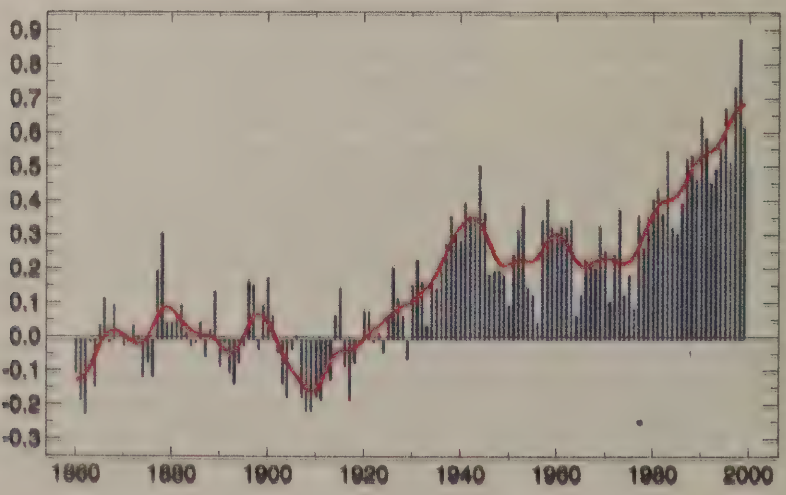


Figure 1: The global-mean, annual average, surface temperature from 1860–1999, relative to that at the end of the 19th century (blue bars), together with a smoothed curve (red) showing the long-term trend. (*Source:* The Met Office Hadley Centre and University of East Anglia).

---

[3] Not printed.

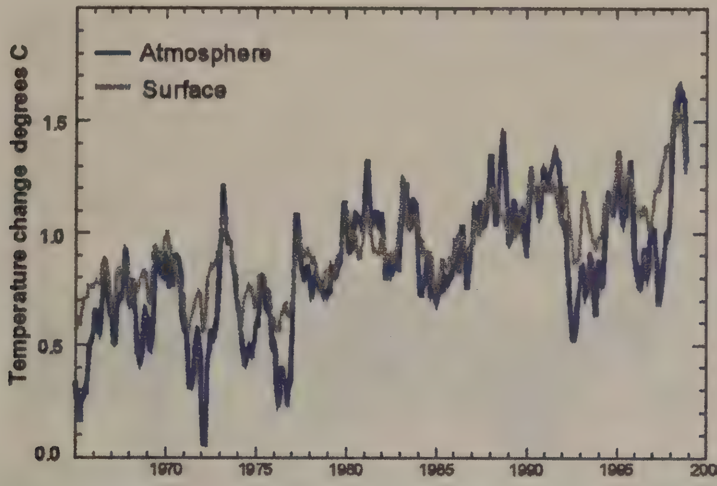


Figure 2: The global temperature change from 1965–1998, (a) at the surface (grey line) and (b) 3-5 km up in the atmosphere (blue line). (*Source:* The Met Office Hadley Centre).

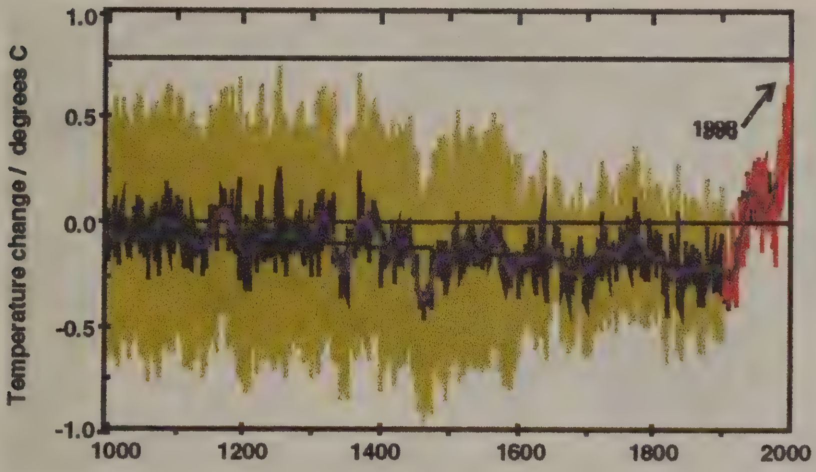


Figure 3: A reconstruction of Northern Hemisphere annual average temperature change from 1000 to 1998 (purple), with the range of uncertainty in yellow. The last 100 years, shown in red, are the same instrumental record as in Figure 1. (*Source:* Professor Michael Mann, University of Massachussets).

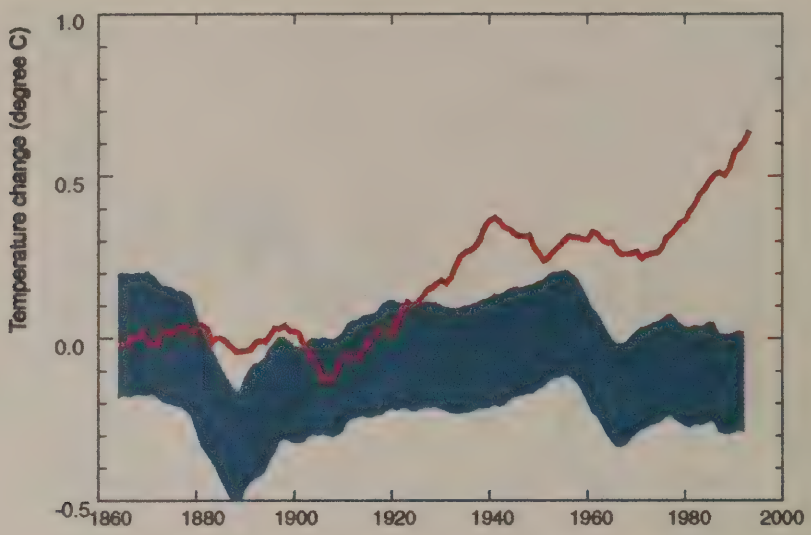


Figure 4: Model simulation of the range of global temperature change 1860–1998 due only to natural variability, solar activity and volcanoes (blue band), compared to observations (red line). The model simulation is inconsistent with observations, suggesting that recent climate change is not natural. (*Source:* The Met Office Hadley Centre).

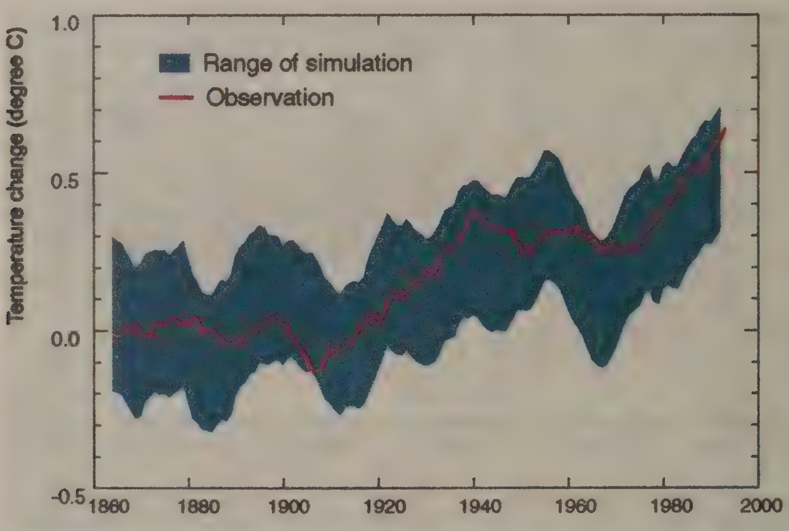


Figure 5: Model simulation of the range of global temperature change 1860–1998 due to the combination of natural factors and human activities (blue band), compared to observations (red line). The simulation is consistent with recent climate change, suggesting that human factors have contributed to the recent change. (*Source:* The Met Office Hadley Centre).

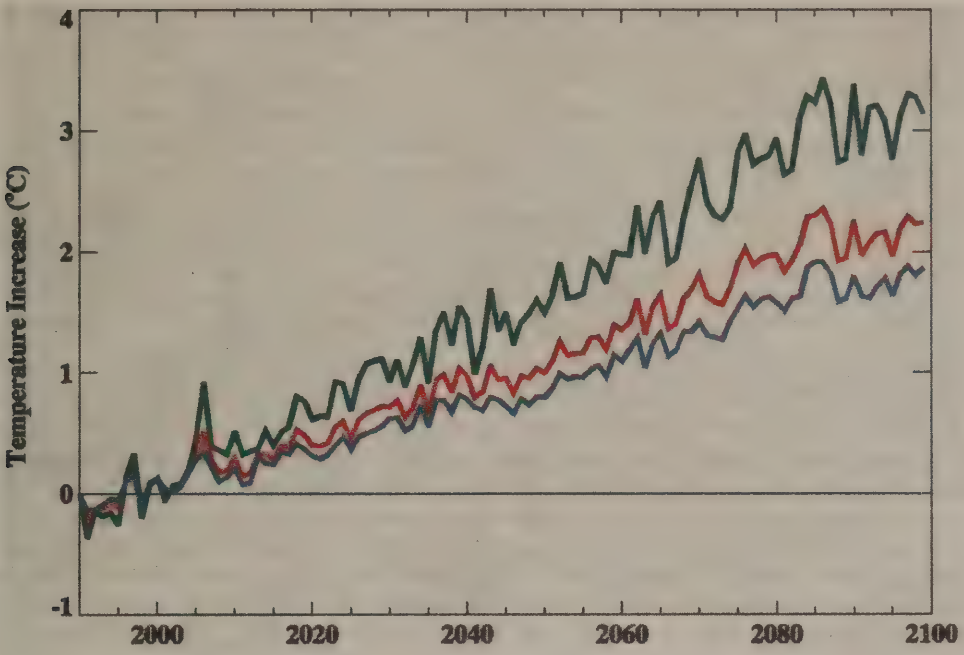


Figure 6: Prediction of temperature rise resulting from the IPCC "B2" emissions scenario, global average (red), over land (green) and over sea (blue). (*Source:* The Met Office Hadley Centre).

To investigate the robustness of this prediction, various idealised experiments are being carried out with the model, so that the reasons for the stability of ocean circulation can be understood.

6.18 Finally, it is always possible that, because of climate processes of which we are unaware and which are therefore not represented in models, climate could change in a way very different from model predictions. This is analogous to the case of the ozone hole, which was not predicted by 1980s models of stratospheric ozone depletion as scientists were ignorant of the type of process which created it (chemical reaction on ice surfaces). That the climate model is able to simulate changes over the past 100 years shows that this is unlikely, but cannot be ruled out, and provides part of the rationale for ongoing research.

7: *Conclusion on models of climate change*

Global climate models are the most scientifically comprehensive tools available for analysing climate and predicting change. The Met Office's Hadley Centre climate model, used as the basis of advice to Government, is recognised as being world–leading. It has been comprehensively evaluated by examining its ability to:

- maintain a stable realistic climate over a 1000 year timescale
- reproduce the temperature trends over the last 150 years
- give realistic representations of natural climate variability such as El Niño
- be used successfully in an essentially similar form as a weather forecasting model
- represent different palaeoclimate epochs.

SECTION C: ADVICE TO GOVERNMENT ON CLIMATE CHANGE

8. *Advice to Government from The Met Office Hadley Centre*

8.1 Work carried out by The Met Office's Hadley Centre is defined each year with MoD and DETR, based on their requirements including those to inform policy development. Results from the programme enable Government to base its climate change policy on a sound scientific footing. Additionally, because of the internationally recognised quality of the research, it allows the UK to speak with authority and weight at the negotiations for reduction of greenhouse gas emissions under the UN Framework Convention on Climate Change. For example, the Deputy Prime Minister's statement to the November 1999 Bonn Conference of Parties to the Convention specifically referred to Hadley Centre results in calling for more rapid progress towards implementing the Kyoto Protocol.

8.2 The DETR contract contains an annex specifically devoted to communication of research results and advice to Government, and contact with DETR staff is on a daily basis. Communication comes in several main forms:

- DETR receive specific deliverables which are part of the contract; typically about 60 reports per year. The most recent on the attribution of climate change was delivered in May 1999.
- Hadley Centre staff brief DETR science staff on ongoing progress with work and recent results at the earliest opportunity before these have been enshrined in reports.
- Hadley Centre staff give presentations to senior officials and ministers as and when the need and opportunity arise; these have recently included Mr Prescott and Mr Meacher and, under previous Governments, the Prime Minister and Secretaries of State. An example of a recent briefing on climate change attribution, to the Head of Global Atmosphere Division on 16 June 1999, which included a description of the cosmic ray–cloudiness–climate change theory, is at Attachment B.[4]
- Hadley Centre staff respond to ad–hoc requests from DETR, for example in preparing UK responses to draft assessments from IPCC (such as the recent one on the use of carbon sinks within the Kyoto Protocol), in drafting ministerial speeches, or in critiquing media stories.

8.3 The Hadley Centre is able to provide briefing to DETR on the many scientific, pseudo–scientific and non–scientific theories which are put forward, often from sources other than the peer–reviewed scientific literature, which imply predictions of change either much greater or much lower than that from models. Where the arguments are substantial and scientific, and leave cause for doubt, the briefing is followed up with a more detailed assessment and, in some cases, a programme of research. Scientific controversies which we have addressed in detail over the past 5 years (the scientific aspects of which have, in some cases, been covered in Section 3) include:

- why is there no apparent satellite data does not show any indication of global warming?
- has recent warming been due to changes in solar activity?
- will the UK become colder, following a shut–down of the Gulf Stream due to climate change?
- is amplification of change from water vapour feedback much less than in climate models?
- will hurricanes and storms increase dramatically as global warming advances?
- will sea-level rise by several metres over the next 100 years?
- are many recent global weather disasters due to climate change?
- is the rise in CO_2 concentration over the last 200 years natural?

8.4 Hadley Centre staff also brief officials and ministers of other government departments. In the past 10 years this has included FCO, MoD, MAFF, Department of Health, DfID/ODA and DTI; Annex D[5] lists briefings to ministers and senior advisors. We have also made contributions to assessments by MoD, Department of Health and MAFF of the impacts of climate change on their departmental interests.

8.5 At the request of DETR, easily-accessible reports for wider circulation are produced from time to time. To illustrate not only changes in climate, but also the impacts these might have for socio–economic sectors, the Hadley Centre has published booklets to coincide with the last three Conferences of Parties to the UNFCCC. Briefings are also regularly given to business (particularly oil companies and utilities), pressure groups, overseas governments and the media.

8.6 The content and progress of the programme of work of the Hadley Centre is kept under review by a Science Review Group, consisting of leading experts in the UK in the topics covered by the Programme, which meets twice a year. In addition, a more general review, including the involvement of international experts, was carried out in 1995 and is underway in 2000.

8.7 We have good reason to believe that the advice given on climate change is accepted by Government, and makes a substantial impact on the development of UK policy on climate change, for the following reasons:

- The Hadley Centre is requested by DETR to participate in the annual Conference of Parties to the UN Framework Convention on Climate Change, and has given presentations on scientific developments at all five of them so far.
- As mentioned above, Government frequently alludes to results from Hadley Centre research in furtherance of its policy.
- The content of Government responses and Ministerial speeches include input submitted by Hadley Centre staff.
- Our contributions to assessments made by a number of Government departments have appeared in official reports.

---

[4] Not printed.

[5] Not printed.

9. *Advice to Government from the Intergovernmental Panel on Climate Change*

9.1 In addition to direct advice based on research carried out at the Hadley Centre, Government is also able to draw on international assessments undertaken by the Intergovernmental Panel on Climate Change (IPCC). These assessments provide the common scientific, technical and socio–economic background to negotiations of Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The IPCC is organised into three working groups and a task force on national greenhouse gas inventories. Working Group I assesses the scientific aspects of the climate system and of climate change. Group II addresses the vulnerability of human and natural systems to climate change, the negative and positive consequences of climate change, and options for adapting to them. Group III assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change.

9.2 The IPCC produces a range of reports and assessments to meet the information needs of policymakers. Comprehensive assessments reports are produced about every five years; the next one will be in 2001. About 400 of the world's leading experts, from 120 countries, are directly involved in drafting, revising and finalising these. In addition, about 2,500 experts participate in reviewing the reports as they are being prepared. Each working group report also contains a 30–50 page Technical Summary, and a 5–10 page Summary for Policymakers which summarises the key findings in a non-technical style. These Summaries for Policymakers are approved line-by-line by governments (with the concurrence of the lead authors) at an intergovernmental meeting. There is also a Synthesis Report which provides a policy relevant synthesis and integration of the three working group reports.

9.3 In addition to the major reports the IPCC also publishes Special Reports and Technical Papers, which address topics on which governments request a scientific or technical perspective. Through its worldwide network of experts the IPCC seeks to reflect the full range of scientific-technical views and expertise. One of the fundamental principles of IPCC is that its reports should provide accurate, unbiased, policy relevant, but not policy prescriptive information. By following this principle, and through the rigorous drafting and approval process, IPCC products have become standard works of reference, widely used by policy makers, scientists and other experts. Hence, IPCC is one of the processes which Government uses to obtain scientific advice on climate change.

9.4 The Hadley Centre is heavily involved in all aspects of the IPCC process. The 1995 assessment was greatly influenced by new results from the Hadley Centre, and this is likely to be the case in the current assessment. Sir John Houghton is currently co-chair of IPCC Working Group I, and has been since the IPCC was established in 1988. The UK government (DETR) provides funds to support the work of IPCC, through direct contributions and through the provision of the Technical Support Unit, located at the Hadley Centre, which manages the work of IPCC Working Group I.

9.5 Advice to Government from IPCC carries a broader consensus, and covers a wide range of topics, than Government's own research programmes, such as that at the Hadley Centre. On the other hand, the Hadley Centre programme is more tuned to the specific needs of the UK Government, can respond quickly (in hours if necessary), and provide advice which may be clearer than that which is allowed under the IPCC requirement of consensus.

10. *Conclusion on advice to Government, and its acceptance*

We are confident that results from the programme of research work carried out by The Met Office's Hadley Centre, including the issue of the causes of recent climate change, are and have been recognised, accepted and used effectively by Government. We believe that the high scientific standard of this research, taken together with the broader consensus from IPCC assessments, has substantially influenced the development of UK policy on climate change, and has impacted on international negotiations on reduction of greenhouse gas emissions.

February 2000

APPENDIX 9

Memorandum submitted by the Economic and Social Research Council (ESRC)

INTRODUCTION

1. The Economic and Social Research Council is a research funding agency, established by Royal Charter. Our mission is to promote and support high quality basic strategic and applied research in the social sciences, which meets the needs of users and beneficiaries. Over 65 per cent of our investments are guided by themes that reflect scientific and national priorities. These themes are reviewed regularly and are developed in consultation with academics, learned societies and research users in business, government and the voluntary sector.

2. At present, the ESRC has nine themes, one of which is Environment and Sustainability. Under this theme, two major investments that encompass issues of climate change have been funded over the past 10 years. These are the Programme on Global Environmental Change (GEC) co-ordinated at the University of Sussex and the Centre for Social and Economic Research on the Global Environment (CSERGE) at the University of East Anglia and University College London.

3. The ESRC has funded a considerable volume of high quality research that has acquired national and international recognition for its contribution to the understanding issues relating to climate change.

SUPPORTED RESEARCH AND VALIDITY OF CLIMATE CHANGE MODELS

4. A list of the specific research grants, programmes and centres related to climate change research may be found in Annex 1. The focus of the research at CSERGE has been to examine the inter-relationships between social and economic factors and the resulting climatic changes, rather than on specific climate models. However, CSERGE note the relative shortfall of research on "regional" scale predictions, in particular the uncertainty of the magnitude of climate change impacts on this scale. A complete listing of the projects and outputs derived from CSERGE may be found in their detailed response to the Committee's concerns at Annex 2.

5. The GEC Programme has supported a broad range of research related to climate change. Topics include examining government regulations and economic instruments, transportation challenges and renewable energy impacts on climate change. One specific award to Robin Grove White and colleagues at the University of Lancaster supported under the GEC Programme and recorded in Annex 1 has addressed uncertainty with specific reference to the use of climate change models. Notable conclusions of this work include: "the common relative ordering of different climate models—which champions global climate models as the "ultimate" climate model—is not fully justified by scientific arguments alone, at least not for the simulation and projection of future climate change . . . the mutual reinforcement of particular scientific and policy approaches . . . will also raise questions about the relative merits of alternative scientific methods and styles . . . the definition of "good science" has held back some of the alternative approaches which could be further developed and used profitably in the widening climate science and policy domain." (Quotations from Shackley *et al,* Uncertainty, Complexity and Concepts of Good Science in Climate Change Modelling: Are GCMs the Best Tools?, Climatic Change 38 pp 159–205, 1998).

6. The ESRC in partnership with the Natural Environment Research Council and Engineering and Physical Sciences Research Council, will be investing in a new Climate Change Centre this year which will provide new options for examining the interdependencies between the natural, social and economic environments.

ALTERNATIVE EXPLANATIONS FOR CLIMATE CHANGE TRENDS

7. The focus of ESRC-funded research has been on the economic and social contributions to—and consequences of—climate change, including the implications of scientific uncertainty, as noted above. However, the ESRC is not in a position to comment directly on alternative scientific explanations of climate change trends.

DISSEMINATION TO GOVERNMENT

8. ESRC funded research has contributed considerably to government policy at both national and international levels. These contributions have been made in publications, commissioned research and reports, submissions to inquiries, and through politician and official participation in numerous workshops and seminars organised by CSERGE and the GEC Programme. Many different communication methods have been used according to the audience. Full details of the outputs from CSERGE, for example are listed in Annex 2.

9. Of particular note are the contributions by CSERGE to the Intergovernmental Panel on Climate Change (both in 1995 and the current work) and its advisory role to the United Nations Environment Programme.

10. The Department of Environment, Transportation and the Regions have provided funding directly to CSERGE to develop scenarios which would assist regional and national policy-making. In addition, regionally based policy makers have participated in workshops to evaluate proposed socio-economic and climate scenarios in the East Anglia region and important contributions have been made to work on a European level. Paragraph 12 in Annex 2 gives further details.

11. The GEC Programme has been actively involved in making submissions to several parliamentary Committees. In 1999 these included the Environment Committee's Inquiry into the UK Climate Change Programme and the Environmental Audit Select Committee Inquiry into the UK Sustainable Development Strategy (1999).

12. The GEC Programme also published a Special Briefing in 1997 entitled "*After Kyoto: Making Climate Policy Work*" which was disseminated to almost 4,000 interested academics, government agencies as well as non-governmental organisations.

Annex 1

List of Relevant ESRC-Funded Research on Climate Change

Principal Investigator	*Institution*	*Title*	*Discipline*	*Amount £K*	*Duration*
Individual Grants					
Dr S. N. Solomou	University of Cambridge	The Impact of Climate on Agricultural Output & Productivity, 1884–1990	Economics	£27.9	01–11–94–31–10–95
Dr S. J. Shackley	University of Lancaster	Science, Knowledge & Environmental Policy	Sociology	£4.8	15–10–95–14–06–97
Dr J. R. Broome	University of Bristol	Intergenerational Aspects of Climate Change	Economics	£5.8	01–01–91–31–03–91
Research Centres					
Prof. Kerry Turner	University of East Anglia	Centre for Social and Economic Research on the Global Environment		£2,790	1996–2001 (Second 5 years of funding)
Global Environmental Change Programme Director Award					
Dr Frans Berkhout	University of Sussex	Global Environmental Change		£20,000	Ends 2000
Global Environmental Change Programme Individual Awards					
Dr S. A. Boehmer-Christianser	University of Sussex	The Formulation and Impact of Scientific Advice on Global Climate Change	Planning	£85.2	01–10–91–31–03–94
Dr M. Douglas	University of Oxford	Human Needs and Wants—A Driving Force for Climate Change	Social Anthropology	£36.3	01–12–93–30–06–95
Mr O. J. Greene	University of Bradford	Verification and Information Exchange in the Development of a Global Warming Regime	Political Science	£68.9	01–01–91–31–03–91
Prof. R. B. Grove-White	University of Lancaster	Science, Culture & the Environment	Sociology	£543.7	01–04–94–03–11–97
Prof. D. Anderson	Imperial College London	Technical Progress, Innovation and Environmental Policy Analysis—A Quantitive Framework	Economics	£92.2	01–09–97–31–08–99
Dr F. Drake	University of Leeds	GEC and European Business: Atmospheric Change, Reactions and Responsibilities	Human Geography	£82.8	01–04–96–30–06–98
Dr I. A. Newman	University of Loughborough	UK Global Environmental Change Data Network Facility	Statistics	£747.6	01–04–92–31–03–95

Annex 2

The Centre for Social and Economic Research on the Global Environment

1. Research on climate change has been a central theme of both economic and interdisciplinary research within CSERGE. The objectives have been to examine the causes and consequences of climate change at global and local scales and to derive policy implications for the UK EU and other regions. The research has led to theoretical development and understanding of climate as a global environmental issue as well as insights into the fundamental role of mitigation and adaptation strategies and resilience capacity across different spatial and temporal scales. The importance of this research area reflects the reality that climate change is a key long term environmental regulatory issue. This is both because of the importance of adaptation to increase climate risks and because decoupling of economic activity from energy intensity is an important sustainability goal in both climate and other contexts. Some of the most important collaborative links in this field have come through interdisciplinary research such as with the Climatic Research Unit and Centre for Environmental Risk at UEA. These links have ensured that researchers from both social and natural science traditions have developed understanding of the broader climate change policy and scientific debates while ensuring that they remain at the forefront of cutting edge developments.

2. This research work has not concentrated specifically on the question of the scientific validity or otherwise of the global climate circulation models. However, much of the work has highlighted the need for "regional" scale climate predictions and problems caused by the current uncertainty that surrounds the magnitude and significance of climate change impacts at the "regional" scale and below. The Centre has also looked at decision-making procedures given the existence of this scientific and social/political uncertainty.

3. CSERGE's work has not been orientated towards an assessment of alternative scientific explanation of climate change. However, it has been investigating the interconnections between the different factors that in combination provide the impacts profile. For example, there are strong impacts links between climate change and ozone depletion in the context of lifestyle and recreation/tourism adaptations and potential human health risks (see CSERGE Working Paper PA 98–05: I Langford, S Moulden-Horrocks, R J Day, A L McDonald, I Bateman and C Saunders, 1998. *Perceptions of Risk of Malignant Melanoma Skin Cancer from Sunlight: a comparative study of young people in the UK and New Zealand,* pp 20).

4. The majority of CSERGE work in the area of climate since 1991 has focused on two issues—the relevance of a climate change agreements as a international means of reducing potential impacts; and the impacts of climate change. By way of illustration, research on the first of these (mitigating measures and reduction of emissions explored both emissions and policies directly as well as exploring the integration of emission reduction with other environmental goals—the so-called secondary benefits of climate control and the double dividend debates. This latter work demonstrated empirically that policy measures in the European context are desirable from a broad environmental perspective, hence contributing to the debate on potential carbon taxes in Europe. Policy research in the period following the signing of the Framework Convention on Climate Change (FCCC) in 1992 also demonstrated potential double dividend benefits of carbon taxes.

5. A large amount of research concentrated on the important interaction of greenhouse gases with land use. This issue highlighted the equity and historical responsibility issues in the causes of climate change. Comprehensive research in this area developed an understanding of policy measures and models of the carbon cycle through changing land use. The first inventory of total carbon fluxes from the UK which included land use change, hence relevant to commitments under the FCCC, was published in *Ambio.* Interdisciplinary modelling showed that UK afforestation and other land use change in the post war period had been a net source of carbon to the atmosphere rather than a sink. Policy measures for methane reduction were also considered. These were published in interdisciplinary journals and in a major monograph entitled *Land Use and the Causes of Global Warming.*

6. The major economic efficiency argument for policy action on climate change requires an assessment of both costs and benefits of avoiding potential climate change impacts. CSERGE researchers pushed forward the boundaries of knowledge in this area by developing models based on stochastic distributions of likely impacts rather than previously used assessments of mean or best guess impacts, which the climate change scientific community had highlighted as being inadequate. At the global scale this work generated controversy in the political context of the IPCC, but argued categorically that economic analysis has a clear role to play in policy development and understanding of the issue. CSERGE has looked further into the efficiency and equity trade-offs that were highlighted during the IPCC debates. Major papers in this area were published in interdisciplinary journals such as *Environment and Planning A. Energy Policy, Energy Journal, Environment and Development Economics,* and *Environmental and Resource Economics,* and a successful Earthscan volume entitled *Valuing Climate Change: the Economics of the Greenhouse.*

7. CSERGE research on climate change has been responsive to the changing policy environment and in tandem has developed theoretical insights. The FCCC through the 1990s has shown that monitoring and enforcement and implementation are key issues. In addition, the 1995 IPCC second assessment report concluded that there was perceptible anthropogenic climate change and hence the world is committed to future uncertain impacts. Thus the CSERGE climate research agenda has developed in the current phase of CSERGE to examine issues of compliance and monitoring and understanding of adaptation and resilience of social systems.

8. Research funded by the GEC Programme has focused on developing an interdisciplinary understanding of social vulnerability to climate change. The empirical part of this work has focused on Vietnam and small island states. CSERGE was a major contributor to the Commonwealth Secretariat's work on vulnerability, including the vulnerability to climate change. Through present day and historical analogy the Vietnam work has demonstrated that the social resilience to climate change is determined by the structure of the economy mediated by the institutional context. In Vietnam this institutional context is evolving rapidly in the transition from central planning to market economy and has been demonstrated to lead to significant changes in dimensions of vulnerability and social resilience to climatic extremes. Vietnam is an agrarian centrally planned country in the process of transition to a market economy. The impact of short term variability and extreme events in Vietnam is maximised when it coincides with external social forces which cause disruptive change. The analysis has highlighted the winners and losers in adaptation, based on the concepts of entitlement and social vulnerability. Vulnerability is defined as the exposure of individuals or collective groups to livelihood stress as a result of the impacts of climate extremes and climate change. The field based research in a district in northern Vietnam indicated that baseline social vulnerability has been increased because of the economic transitions to a market economy ie the breakdown of collective community-scale action to mitigate coastal flooding and erosion; incremental income inequality, and increased investment in enterprises such as aquaculture, which in some ways is more at risk than more traditional farming enterprises. Offsetting these trends are other institutional changes which are serving to decrease vulnerability on a longer term basis. This research was appraised as "outstanding" which signifies "high quality research making an important contribution to the development of the subject" (ESRC evaluation, March 1997). The wider development context and the management of environmental risk in the context of rapid economic growth is explored for this critical region in a forthcoming volume in the Routledge Global Environmental Change series.

9. Research on the amenity value of climate has focused on using revealed preference techniques to uncover the value of marginal changes in climate variables to households, agriculture and British tourists. A paper has analysed the links between land prices in Italy and seasonal values of climate variables such as sunshine, mean temperature and precipitation. In addition research sponsored by the Department of the Environment (now Department of the Environment, Transport and the Regions, DETR) has explored present day analogies to climate change by examining the impact of the 1995 hot summer in the UK in an interdisciplinary study including health, agriculture, tourism and other sectors; and has appraised the impact of mean sea level changes on the UK coast.

10. CSERGE has also undertaken research which integrates several academic disciplines, such as epidemiology, psychology, economics and statistics to gain insight into the links between social, economic and health impacts of global issues such as climate change and ozone depletion. These impacts are intricately interlinked, as perception of risks feeds into attitudinal and behavioural responses to environmental threats which have impacts on people's health and socio-economic status. Methodologies have been applied from epidemiology, using population—averaging approaches to estimate the risk burden from a particular environmental factor; from psychology and economics using individual-based approaches; and from sociology and anthropology, including cultural theory using group-based approaches. These results have then been integrated to give a more holistic picture of the nature of environmental risks, the potential impacts on a particular society and the responses which can be made to counteract adverse effects.

11. Epidemiologically, CSERGE has investigated the health impacts of climate change, such as changes in winter and summer morbidity and mortality from changes in temperature due to global warming, and has undertaken meta-analysis of air pollution. Particular attention has been focused on food poisoning risks, and evidence points to the fact that higher summer temperatures increase the risks to consumers right through the food production process, from the infection burden carried by animals on their way to slaughter, through the food processing industry to the consumer and retail outlets. The impacts of exposure to ultra-violet radiation from sunlight and the incidence of malignant melanoma skin cancer have also been investigated, and different relationships between exposure and incidence have been found in different European countries. These differences depend on attitude to sunbathing, behaviour in hot weather, clothing style and genetic differences, with fair-skinned populations in Northern Europe being at particular risk. Research in CSERGE in collaboration with the Medical Research Council (MRC) Cell Mutation Unit, University of Sussex, has also linked sunlight exposure with increased mutations in human cell lines which may be important in other forms of cancer. Another research strand has focused on the social burden and health impacts of a variety of air pollutants.

12. To date many studies have worked on a combination of future climates scenarios based on present human activities. However, as climate changes, so will the underlying economic, social and environmental contexts in which change is experienced, in a "co-evolutionary" fashion. A new area of research has developed within CSERGE in the last year on the use of scenarios as a tool for exploring adaptation and vulnerability to climate change. UK scenarios developed by SPRU for the Office of Science and Technology were adapted for use in three related projects. The first of these was a DETR funded project to develop non-climate scenarios for a more comprehensive assessment of future possibilities, intended to aid climate change impacts research and national and regional policy-making. Secondly, socio-economic and climate scenarios for the 2020s and 2050s were developed for the East Anglia region in conjunction with the Climatic Research Unit at the University of East Anglia. Expertise of regional stakeholders were called upon in individual interviews

and two group workshops to assess the usefulness and practicality of the scenario approach, as a research tool and an aid for decision makers in thinking about the future climate with a view to their present activities. Also, the framework of the scenarios developed at UK level was used as a basis for setting out a range of possible "futures" of Europe in terms of social, economic and political characteristics. The aim was to spark discussion among policy-makers and actors on the impact of their operations in the long term and possible changes to their current operations in the view of different possible future outcomes. So far this work has been written up in a report on the ACACIA project (A Concerted Action Towards a Comprehensive Climate Impacts and Adaptation Assessment for the European Union), Parry, M, (ed,) 1999. Assessment of the Potential Effects of Climate Change in Europe (ACACIA Project), October 1999, and in a Report with SPRU to the DETR. It will also feature in contributions to the IPCC Third Assessment Report.

13. Interdisciplinary coastal zone management research at CSERGE, bridging socio-economic and natural sciences, has been undertaken on a range of geographical and institutional levels (global, regional, national and local levels) through partnerships with a number of organisations and networks. At a global level, for example, the Centre remains a leading contributor to initiatives such as the Coastal Zone (LOICZ). Core project of the International Geosphere-Biosphere Programme (IGBP). One of the long-term objectives of this initiative is to assess how the responses of coastal systems to global change will affect the habitation and use by humans of coastal areas and to develop further the socio-economic basis for the integrated management of the coastal environment. CSERGE has been and continues to be instrumental in the development of such methodologies (including the publication of guidelines/handbooks) for evaluation in integrated coastal zone management in order to assist managers and decision-makers. These methodologies are currently being assessed utilising case studies by institutes across the globe.

14. Of the studies undertaken at a national level one example is a project, still in progress, evaluating trade-offs between users or marine protected areas in the Caribbean. Islands such as these are heavily dependent on their natural resource base and as such are vulnerable to environmental change. This work is developing a methodology for assessing conflicts and trade-offs between different uses and user groups thereby providing information about development options to decision makers. Funded by the DfID this work builds on collaborative work between the UEA (Overseas Development Group, School of Development Studies), CSERGE and the University of the West Indies, St Augustine, Department of Zoology.

Dissemination

15. Central to CSERGE's activities is a commitment to communicating and sharing the outputs of its academic research programme as widely as possible and especially to stakeholders and decision-makers in relevant sectors. CSERGE staff have therefore devoted much time and effort to creating and maintaining effective communication and dissemination links. The purpose of the dissemination strategy is to cater for the wide variety of needs displayed by the Centre's user groups, to communicate the findings of the research programmes in different formats and through a range of channels; to be flexible enough to adapt to the changing requirements of established users; and to identify and service new users. CSERGE also sees the sharing of research findings and ideas within the ESRC's GEC Research Programme and other relevant networks as an important component of its work.

16. Consequently, CSERGE climate change research findings have been disseminated widely via a combination of publications of the highest academic standard in peer-reviewed journals and as books/book chapters; publications which are specifically targeted at broader non-academic audiences; public lectures, seminars, conference presentations, training courses and direct advice to government, NGOs, business and other users; networking with others (locally, nationally and internationally), notably in government, NGOs and the active civil society on environmental problems; and in some cases through appearances in the broadcast and print media, and by direct mailing.

17. Through such means the climate change research field has been strongly influenced by CSERGE work on for example international environmental agreements, damage valuation and vulnerability. This has been achieved through the Centre's major contributions to the Intergovernmental Panel on Climate Change (IPCC) and other fora. In the IPCC Second Assessment Report of 1995, CSERGE researchers were convening, lead and contribution authors in four major chapters across Working Groups II and III. CSERGE's climate change work has also received recognition in membership of the Scientific Organising Committee, United Nations Staff College Project on International Environmental Agreements, Turin, 1997–98 and an advisory role to the United Nations Environment Programme, Effectiveness of Multilateral Environmental Agreements Committee 1997-98. The high profile of this work has continued recently with contributions to IPCC special reports and working groups, including the 1998 Costa Rica meeting on Adaptation to Climate Variability and Change. CSERGE researchers also contributed to the Batelle Institute study of social sciences and climate change, as well as to a number of International Geosphere Bioshpere (IGBP) programmes, most notably Land Ocean Interface in the Coastal Zone (LOICZ) and the International Human Dimensions Programme (IHDP). In Europe, research has been carried out for EU DGVI (Agriculture) on climate change mitigation strategies for land use resulting in the volume *Climate Change Mitigation and European Land Use Policies.*

18. In the UK the regional climate change scenarios work mentioned above has been disseminated via two presentations: a Workshop: "Future changes in the East Anglian region", hosted by the Environment Agency Anglian Region, Peterborough, 30 April 1999; and a Conference "A better quality of life. The future of sustainable developments in the East of England", 22 October 1999, held to launch the new East of England Sustainable Development Round Table.

ISBN 0-10-217501-2

9 780102 175011

Distributed by The Stationery Office Limited
and available from:

The Stationery Office
(Mail, telephone and fax orders only)
PO Box 29, Norwich NR3 1GN
General enquiries 0870 600 5522
Order through the Parliamentary Hotline *Lo-call* 0845 7 023474
Fax orders 0870 600 5533
Email book.orders@theso.co.uk
Internet http://www.ukstate.com

The Stationery Office Bookshops
123 Kingsway, London WC2B 6PQ
020 7242 6393 Fax 020 7242 6394
68–69 Bull Street, Birmingham B4 6AD
0121 236 9696 Fax 0121 236 9699
33 Wine Street, Bristol BS1 2BQ
0117 9264306 Fax 0117 9294515
9–21 Princess Street, Manchester M60 8AS
0161 834 7201 Fax 0161 833 0634
16 Arthur Street, Belfast BT1 4GD
028 9023 8451 Fax 028 9023 5401
The Stationery Office Oriel Bookshop
18–19 High Street, Cardiff CF1 2BZ
029 2039 5548 Fax 029 2038 4347
71 Lothian Road, Edinburgh EH3 9AZ
0870 606 5566 Fax 0870 606 5588

The Parliamentary Bookshop
12 Bridge Street, Parliament Square
London SW1A 2JX
Telephone orders 020 7219 3890
General enquiries 020 7219 3890
Fax orders 020 7219 3866

Accredited Agents
(See Yellow Pages)

and through good booksellers

© Parliamentary Copyright House of Commons 2001
Applications for reproduction should be made in writing to the Copyright Unit,
Her Majesty's Stationery Office, St Clements House, 2–16 Colegate, Norwich NR3 1BQ
– Fax 01603 723000

ISBN 0 10 217501 2